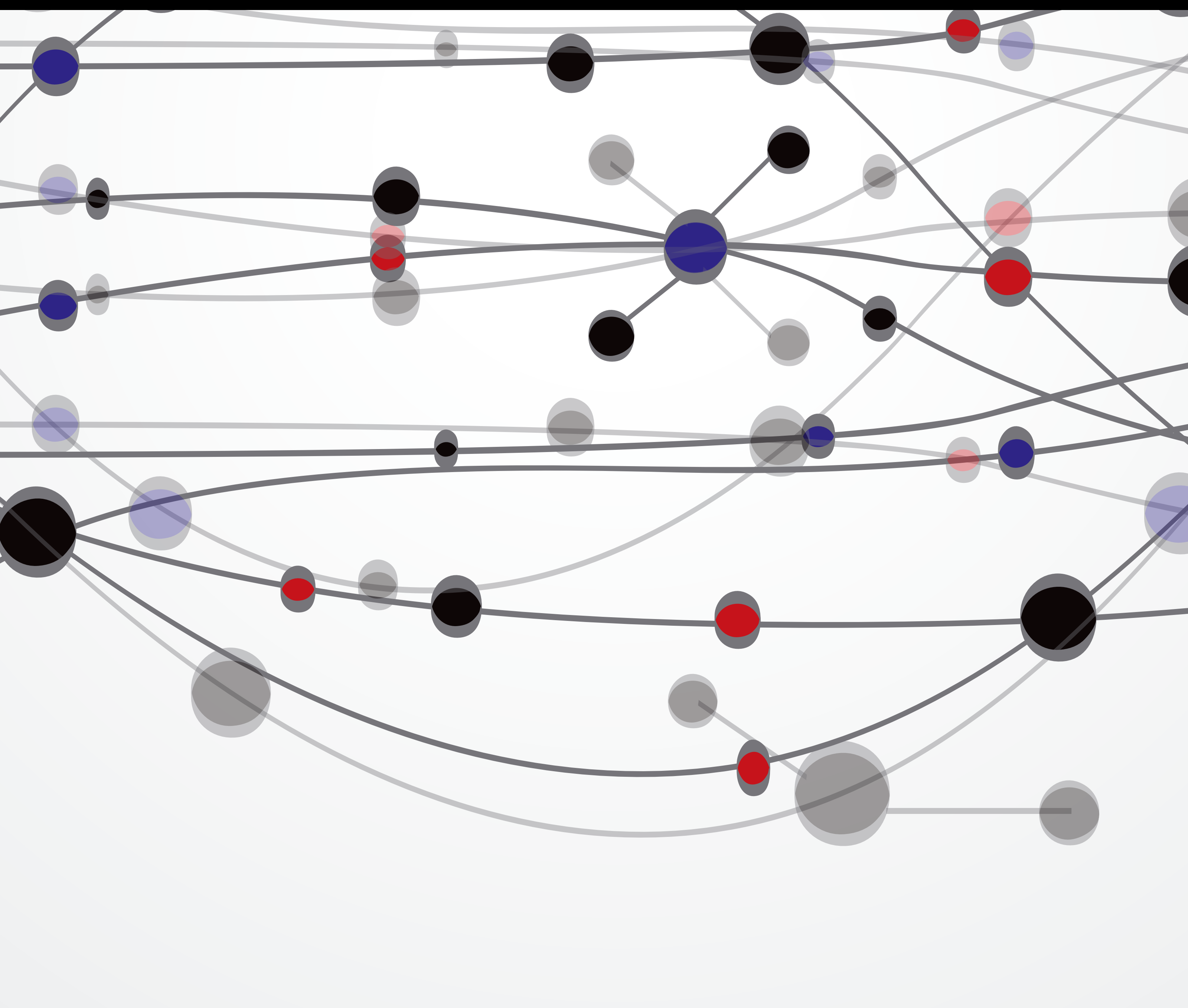
The Scientific World Journal

Recent Trends and Techniques in Computing Information Intelligence

Guest Editors: Venkatesh Jaganathan, Balasubramanie Palanisamy, and Mariofanna Milanova



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Editorial

Recent Trends and Techniques in Computing Information Intelligence

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Computing information intelligence is considered an extremely important asset to any organization. Techniques are set of management disciplines with the help of computing information that allow organizations to manage their technological fundamentals to create competitive business advantage. Computing information intelligence includes integrated planning, design, optimization, operation, and control of technological products, processes, and services: a better definition would be the management of the use of intelligence for human advantage. Information and computing intelligence sciences employ new technologies to solve client problems through contract research. To address the problems a lot of research efforts are still needed from both academia and industry. This special issue aims to promote research in the area of computing information intelligence in present business scenario.

The article entitled "Information Retrieval and Graph Analysis Approaches for Book Recommendation" proposed a combination of multiple information retrieval approaches for the purpose of book recommendation. Different theoretical retrieval models, probabilistic as InL2 (divergence from randomness model) and language model, are used and we tested their interpolated combination. Graph analysis algorithms such as PageRank have been successful in Web environments. We consider the application of this algorithm in a new retrieval approach to related document network comprised of social links. A series of reranking experiments demonstrate that combining retrieval models yields significant improvements in terms of standard ranked retrieval metrics.

The article entitled "Distilling Big Data: Refining Quality Information in the Era of Yottabytes" targets the utilization of the Fuzzy Bayesian process model to improve the quality of information in Big Data.

The article entitled "Framing a Knowledge Base for a Legal Expert System Dealing with Indeterminate Concepts" describes the development of a negotiation decision support system (the Parenting Plan Support System or PPSS) to support parents in drafting an agreement (the parenting plan) for the exercise of parental custody of minor children after a divorce is granted.

In the article entitled "Priority Based Congestion Control Dynamic Clustering Protocol in Mobile Wireless Sensor Networks," in order to conserve energy and to avoid congestion during multiclass traffic a novel Priority Based Congestion Control Dynamic Clustering (PCCDC) protocol is developed. Simulation results have proven that packet drop, control overhead, and end-to-end delay are much lower in PCCDC which in turn significantly increases packet delivery ratio, network lifetime, and residual energy when compared with PASCC protocol.

The article entitled "Predicting Defects Using Information Intelligence Process Models in the Software Technology Project" gave the practical applicability of using predictive models and illustrated the use of these models in a project to predict system testing defects, thus helping to reduce residual defects.

The article entitled "Scalable Clustering of High-Dimensional Data Technique Using SPCM with Ant Colony Optimization Intelligence" has been developed to cluster data using high-dimensional similarity based PCM (SPCM), with ant colony optimization intelligence which is effective in clustering nonspatial data without getting knowledge about cluster number from the user. The mountain method is applied for searching approximate centers in the cluster, where the maximum density clusters are located. Though this is efficient clustering, it is checked for optimization using ant colony algorithm with swarm intelligence. Thus, the scalable clustering technique is obtained and the evaluation results are checked with synthetic datasets.

In the article titled "Multicriteria Personnel Selection by the Modified Fuzzy VIKOR Method" personnel evaluation is an important process in human resource management; a fuzzy hybrid multicriteria decision-making (MCDM) model is proposed to personnel evaluation. This model solves personnel evaluation problem in a fuzzy environment where both criteria and weights could be fuzzy sets. The triangular fuzzy numbers are used to evaluate the suitability of personnel and the approximate reasoning of linguistic values. A comparative analysis of results by fuzzy VIKOR and modified fuzzy VIKOR methods is presented. Experiments showed that the proposed modified fuzzy VIKOR method has some advantages over fuzzy VIKOR method. Firstly, from a computational complexity point of view, the presented model is effective. Secondly, compared to fuzzy VIKOR method, it has high acceptable advantage compared to fuzzy VIKOR method.

The article entitled "Traffic and Driving Simulator Based on Architecture of Interactive Motion" proposes an architecture for an interactive motion-based traffic simulation environment. The architecture has been designed to enable the simulation of the entire network; as a result, the actual driver, pedestrian, and bike rider can navigate anywhere in the system. The two traffic flow simulation models interact continuously to update system conditions based on the interactions between actual humans and the fully simulated entities. The implementation of the proposed architecture faces significant challenges ranging from multiplatform and multilanguage integration to multievent communication and coordination.

The article entitled "Proactive Alleviation Procedure to Handle Black Hole Attack and Its Version" proposed an alleviation procedure which consists of timely mandate procedure, hole detection algorithm, and sensitive guard procedure to detect the maliciously behaving nodes. It has been observed that the proposed procedure is cost-effective and ensures QoS guarantee by assuring resource availability, thus making the MANET appropriate for Internet of Things.

Overall, this special issue brought together state-of-the-art research contributions, tutorials, and position papers that address the key aspects of computing information intelligence towards the recent trends and techniques.

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Research Article

Intelligent Soft Computing on Forex: Exchange Rates Forecasting with Hybrid Radial Basis Neural Network

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This paper deals with application of quantitative soft computing prediction models into financial area as reliable and accurate prediction models can be very helpful in management decision-making process. The authors suggest a new hybrid neural network which is a combination of the standard RBF neural network, a genetic algorithm, and a moving average. The moving average is supposed to enhance the outputs of the network using the error part of the original neural network. Authors test the suggested model on high-frequency time series data of USD/CAD and examine the ability to forecast exchange rate values for the horizon of one day. To determine the forecasting efficiency, they perform a comparative statistical out-of-sample analysis of the tested model with autoregressive models and the standard neural network. They also incorporate genetic algorithm as an optimizing technique for adapting parameters of ANN which is then compared with standard backpropagation and backpropagation combined with K-means clustering algorithm. Finally, the authors find out that their suggested hybrid neural network is able to produce more accurate forecasts than the standard models and can be helpful in eliminating the risk of making the bad decision in decision-making process.

1. Introduction

Techniques of artificial intelligence and machine learning started to apply in time series forecasting. One of the reasons was the study of Bollerslev [1], where he proved the existence of nonlinearity in financial data. First models of machine learning applied into time series forecasting were artificial neural networks (ANNs) [2]. This was due to the fact that the artificial neural network is a universal functional black-box approximator of nonlinear type [3–5] that is especially helpful in modeling of nonlinear processes having a priori unknown functional relations or system of relations is very complex to describe [6] and they are even able to model chaotic time series [7]. They can be used for nonlinear modeling without knowing the relations between input and output variables. Thanks to this, ANNs have been widely used to perform tasks like pattern recognition, classification, or financial predictions [8–11]. Following the theoretical knowledge of perceptron neural network published by McCulloch and Pitts [12] and Minsky and Papert [13], nowadays, it is mainly radial basis function (RBF) network [14, 15] that has been used as it showed to be better approximator than the basic perceptron network [16–18].

In this work we extend the standard RBF model by using moving average for modeling the errors of RBF network. We chose the RBF neural network for our exchange rates forecasting experiment because according to some studies [19] ANNs have the biggest potential in predicting financial time series. In addition, Hill et al. [20] showed that ANNs work best in connection with high-frequentional financial data. Moreover, we will combine the standard ANN with EC technique called genetic algorithms. As, according to some scientists [21], the use of technical analysis tools can lead to efficient profitability on the market, we decided to combine our customized RBF network with moving averages [22]. We will use the simple moving average to model the error part of the RBF network as we supposed it could enhance the prediction outputs of the model.

Applying the prediction analysis, the forecasting ability of this nonlinear model will be compared and contrasted with a standard neural network and an autoregressive (AR) model with GARCH errors to determine the best model parameters for this currency pair forecasting problem. We will provide out-of-sample evidence since it focuses directly on predictability as it is important to avoid in-sample overfitting for this type of nonlinear models [23].

The soft computing application we suggest is novel in two ways; we use the standard neural network hybridized with simple moving averages to form a whole new hybrid model. Except for the standard algorithm for training the neural network, we also use other (advanced) technicqves.

2. Suggested Hybrid-RBF Neural Network Combined with Moving Average

Hybrid models have become popular in the field of financial forecasting in recent years. Since studies from Yang [24] or Clemen [25] theoretically proved that a combination of multiple models can produce better results, we will also use the combined model of customized RBF neural network (supplemented by genetic algorithms for weights adaptation) and simple moving average tool for modeling the error part of the RBF. We eliminate the error of the neural network by modeling the residuals of RBF.

Let F be a function defined as F: $x_t \in \mathfrak{R}^k \rightarrow y_t \in \mathfrak{R}^1$ which is a representation assigning one value y_t to n-dimensional input in a given time period t. Let G be a restriction of F defined as $G(x_t, w_t, v_t, s) : x_t \in \mathfrak{R}^k_{\text{train}} \rightarrow y_t \in \mathfrak{R}^1_{\text{train}}$, where $\mathfrak{R}_{\text{train}}$ is a complement of $\mathfrak{R}_{\text{val}}$ to $\mathfrak{R}$. Then, the hybrid neural network model of RBF(x, w, v, s) and SMA(q) is defined as

$$G\left(x_t, w_t, v_t, s\right) = \psi_2 \sum_{j=1}^{s} \left(v_j o_j\right) + \varepsilon_t^{\text{RBF}}, \tag{1}$$

where

$$o_j = \psi_1 \left[\phi\left(x, w^j\right)\right], \quad j = 1, 2, \ldots, s \tag{2}$$

with

$$\begin{aligned}
\varepsilon_t^{\text{RBF}} &= e_t + u_t, \quad u_t \approx iid\,(0,1), \\
e_t &= \sum_{i=1}^{q} \theta_i \varepsilon_{t-i}^{\text{RBF}}, \quad \sum_{i=1}^{q} \theta_i = 1, \\
E\left(w_t\right) &= \sum_{x_t, y_t \in R^k_{\text{train}}} \left(G\left(x_t, w_t, v_t, s\right) - y_t\right)^2, \\
E\left(w_t\right) &\longrightarrow \min, \\
\varepsilon_t^{\text{RBF-SMA}} &= G\left(x_t, w_t, v_t, s\right) - y.
\end{aligned} \tag{3}$$

The necessary condition is that the model must be adapted to approximate the unknown function F; that is, the model must fulfill the condition that the difference between estimated output produced by the model and the original value is minimal.

x, w, v, s denote the ANN parameters; x is the input vector of the dimension n; w and v are the parameters of the network (also called synapses or weights) and are used for the interconnection of the neural network. The input vector $x_t^T = (x_{1t}, x_{2t}, \ldots, x_{kt})$ forms the input layer of the network; w_j are weights going from the input layer to the hidden layer that is formed by s hidden neurons. In the RBF network, the radial basis function of Gaussian type instead of a sigmoid function is used for activating neurons in hidden layer of a perceptron network. The Gaussian function for activating neurons is for jth hidden neuron defined as $\psi_1(u^j) = e^{-u^j/2\sigma_j^2} = e^{-||x-w^j||^2/2\sigma_j^2}$, $j = 1, 2, \ldots, s$, where σ_j^2 is the variance of jth neuron and u is the potential of the neuron. Furthermore, v_j, $v_j \in R$ are weights between jth hidden neuron and the output layer that is represented by just one neuron (the network output). Activated neurons are weighted by weight vector $v_t^T = (v_{1t}, v_{2t}, \ldots, v_{st})$ in order to get the output of the network counted as $y = \psi_2(u_t) = \sum_{j=1}^{s} v_j o_j$.

3. Methodology

The neural network we used for this research was RBF which is one of the most frequently used networks for regression. RBF has been widely used to capture a variety of nonlinear patterns (see [26]) thanks to their universal approximation properties (see [27]).

In order to optimize the outputs of the network and to maximize the accuracy of the forecasts we had to optimize parameters of ANN. The most popular method for learning in multilayer networks is called backpropagation. It was first invented by Bryson and Ho [28]. But there are some drawbacks to backpropagation. One of them is the "scaling problem." Backpropagation works well on simple training problems. However, as the problem complexity increases (due to increased dimensionality and/or greater complexity of the data), the performance of backpropagation falls off rapidly [29]. Furthermore, the convergence of this algorithm is slow and it generally converges to any local minimum on the error surface, since stochastic gradient descent exists on a surface which is not flat. So the gradient method does not guarantee to find optimal values of parameters and imprisonment in local minimum is quite possible.

As genetic algorithms have become a popular optimization tool in various areas, in our implementation of ANN, backpropagation will be substituted by the GA as an alternative learning technique in the process of weights adaptation. Genetic algorithms (GA), which are EC algorithms for optimization and machine learning, are stochastic search techniques that guide a population of solutions towards an optimum using the principles of evolution and natural genetics [30]. Adopted from biological systems, genetic algorithms are based loosely on several features of biological evolution [31]. In order to work properly, they require five components [32], that is, a way of encoding solutions to the problem on chromosomes, an evaluation function which returns a rating for each chromosome given to it, a way of initializing the population of chromosomes, operators that may be applied to parents when they reproduce to alter their genetic composition, parameter settings for the algorithm, the operators, and so forth. GA are also characterized by basic genetic operators which include reproduction, crossover, and mutation [33]. Given these genetic operators and five components stated above, a genetic algorithm operates according to the following steps stated in [29]. When the components of the GA are chosen appropriately, the reproduction process will continually generate better children from good parents; the algorithm can produce populations of better and better individuals, converging finally on results close to a global optimum. Additionally, GA can efficiently search large and complex (i.e., possessing many local optima) spaces to find nearly global optima [29]. Also, GA should not have the same problem with scaling as backpropagation. One reason for this is that it generally improves the current best candidate monotonically. It does this by keeping the current best individual as part of their population while they search for better candidates.

In addition, as Kohonen [34] demonstrated that nonhierarchical clustering algorithms used with artificial neural networks can cause better results of ANN, unsupervised learning technique will be used together with RBF in order to find out whether this combination can produce the effective improvement of this network in the domain of financial time series. We will combine RBF with the standard unsupervised technique called K-means (see [35]). K-means algorithm, which belongs to a group of unsupervised learning methods, is a nonhierarchical exclusive clustering method based on the relocation principle. The most common type of characteristic function is location clustering. And the most common distance function is Euclidean.

The K-means will be used in the phase of nonrandom initialization of weight vector w performed before the phase of network learning. In many cases it is not necessary to interpolate the output value by radial functions, it is quite sufficient to use one function for a set of data (cluster), whose center is considered to be a center of activation function of a neuron. The values of centroids will be used as initialization values of weight vector w. Weights should be located near the global minimum of the error function (1) and the lower number of epochs is supposed to be used for network training. The reason why we decided to use K-means is that it is quite simple to implement and in addition to that, in the domain of nonextreme values, it is relatively efficient algorithm. In our experiments, the adaptive version of K-means will be used which is defined as follows:

(1) random initialization of centroids in the dimension of input vector,

(2) introduction of input vector x_i,

(3) determination of the nearest from all centroids to a given input,

(4) adaptation of the coordinates of the centroid according to the rule as follows: $c_{j'} = c^*_{j'} + \eta(x_i - c_{j'})$, where j' is the nearest cluster to the introduced input and η is a learning rate parameter,

(5) termination of the algorithm if all inputs were processed or the coordinates of the cluster are not changing anymore.

4. Empirical Research

We chose forex market for our experiments. Our experiment focuses on time series of daily close price of USD/CAD (the data were downloaded from a website http://www.global-view.com/forex-trading-tools/forex-history/) (Canadian dollar versus US dollar), one of major currency pairs, covering a historical period from October 31, 2008, to October 31, 2012 ($n = 1044$ daily observations). Due to validation of a model, data were divided into two parts (Figure 7). The first part included 912 observations (from 10/31/2008 to 4/30/2012) and was used for the model training. The second part of data (5/1/2012 to 10/31/2012), counting 132 observations, was used for model validation by making one-day-ahead ex-post forecast. These observations include new data which have not been incorporated into model estimation (parameters of the model were not changing anymore in this phase). The reason for this procedure is the fact that an ANN can become so specialized for the training set that loses flexibility, hence the accuracy in the test set.

We used our own application of RBF neural network implemented in JAVA with one hidden layer according to Cybenko [36]; the feedforward network with one hidden layer is able to approximate any continuous function. For the hidden layer, the radial basis function was used as an activation function as it has been showed that it provides better accuracy than the perceptron network. We estimated part of the RBF model with several adapting algorithms: RBF implemented with a backpropagation algorithm, a genetic algorithm, and combination of K-means and backpropagation. As for the backpropagation learning, the learning rate was set to 0.001 to avoid the easy imprisonment in local minimum. The number of epochs for each experiment with backpropagation was set to 5000 as this showed to be a good number for backpropagation convergence. The final results were taken from the best of 5000 epochs and not from the last epoch in order to avoid overfitting of the neural network. K-means was used instead of random initialization of weights before they were adapted by backpropagation. Coordinances of clusters were initiated as coordinances of randomly chosen input vector. K-means cycle was repeated 5000 times and the learning rate for cluster adaptation was set to 0.001. The number of clusters was set to the number of hidden neurons.

For GA algorithm the following was needed: a method of encoding chromosomes, the fitness function used to calculate the fitness values of chromosomes, the population size, initial population, maximum number of generations, selection method, crossover function, and mutation method. Our implementation of the genetic algorithm we used for weight adaptation is as follows. The chromosome length was set according to the formula: $D * s + s$, where s is the number of hidden neurons and D is the dimension of the input vector. A specific gene of a chromosome was a float value and represented a specific weight in the neural network. The whole chromosome represented weights of the whole neural network. The fitting function for evaluating the chromosomes was the mean square error function (MSE). The chromosome (individual) with the best MSE was automatically transferred into the next generation. The other individuals of the next generation were chosen as follows: by tournament selection 100 individuals were randomly chosen from the population. The fittest of them was then chosen as a parent. The second parent was chosen in the same way. The new individual was then created by crossover operation. If the generated value from <0, 1 was lower than 0.5 the weight of the first parent at the specific position was assigned to the new individual. Otherwise, the new individual received the weight of the second parent. The mutation rate was set to 0.01. If performed, the specific gene (weight) of a chromosome was changed to a random value. The size of the population and the number of generations for the genetic algorithm were set accordingly to the settings of backpropagation. Based on some experiments, we used the size of the population that equaled 1000 and the number of generations was set to 10.

When the best configuration of the RBF network was found, the RBF error was then modelled in order to minimize the total error of the model. Using moving average, the forecast of the future error of the RBF was counted as an average of last network errors. We used only simple moving average: the weights of the previous network errors had the same weight. To find out the optimal number of the parameters of moving average tool, we used various numbers of previous errors for counting the future (average) value of RBF error.

The numerical characteristic for assessing models called mean squared error (MSE) was used:

$$\mathrm{MSE} = H^{-1} \sum_{h=1}^{H} \left(\hat{Y}_{n-H+h} - Y_{n-H+h} \right)^2, \tag{4}$$

where h is the forecasting horizon and H is the total number of predictions for the horizon h over the forecast period.

In order to make a comparison with standard statistical models, we also performed the empirical Box-Jenkins analysis [37] in order to compare our suggested model with standard statistical model (for details of Box-Jenkins analysis see the appendix). Box-Jenkins analysis focused on the original and differentiated series of daily observations of USD/CAD currency pair covering a historical period from October 31, 2008, to October 31, 2012. The data, as stated above, was downloaded from the following website: http://www.global-view.com/forex-trading-tools/forex-history/. The best results for out-of-sample prediction were achieved with EGARCH (1, 1, 1) model with Gaussian error distribution. Therefore, this model was compared with the neural network models and our suggested model. The volatility of this model is defined as follows:

$$\log(h_t) = -0.172109 + 0.117148 \frac{|\varepsilon_{t-1}|}{\sqrt{h_t}} + 0.037398 \frac{|\varepsilon_{t-1}|}{\sqrt{h_t}} + 0.992135 \log(h_{t-1}). \tag{5}$$

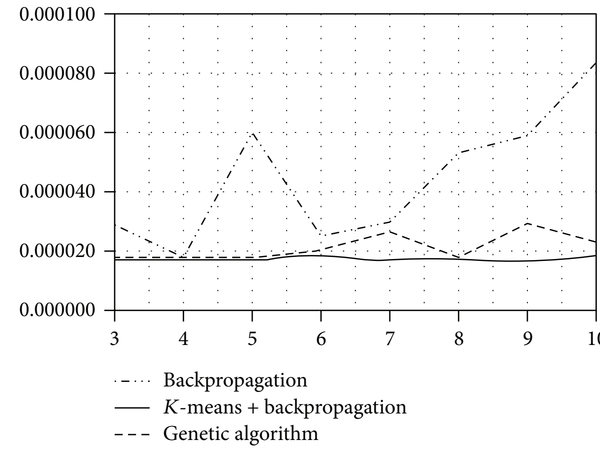


Figure 1: Predictive accuracy of the standard RBF network, AR(1) input.

5. Results and Discussion

The reason why the prediction qualities were applied on the validation set (ex-ante predictions) was the fact that an ANN can become so specialized for the training set that could lose accuracy in the test set. Therefore, the estimation of all models was only based on 912 observations, in order to make further comparisons with the predictions of the 132 remaining observations. In this paper, we only used one-step-ahead forecast: that is, horizon of predictions was equal to one day. In order to eliminate deformation of our results by a single replication we used a procedure applied in Heider et al. [38]; that is, experiment for every model configuration was performed twelve times, the best and worst results were eliminated, and from the rest the mean and standard deviations were counted. The result of a given model is from the best neuron configuration (in every model we tested number of hidden neurons from 3 to 10 to find the best output results of the network).

In Table 1 (RBF network, one autoregressive input), we see that network with BP achieved the best results when having 4 neurons in the hidden layer (see also Figure 1). On the other hand, the advanced methods for network learning (K-means + BP, GA) achieved the best results with 4 (GA), respectively, 9 neurons (K-means + BP). However, when using these advanced methods the number of hidden neurons seemed to not play an important role as the results were comparable. Following from that one can deduce that for remembering the relationships in this time series it is enough to use smaller number of hidden neurons (three or four). When looking at the results of the standard BP, the reason for increasing the error with the higher number of neurons is the fact that the more of the neurons the longer time for the weights adaptions of the network.

Also, the standard BP was the great weakness of the neural network. The convergence is really slow and it generally converges to any local minimum on the error surface, since stochastic gradient descent exists on a surface which is not flat. So the gradient method does not guarantee to find optimal values of parameters and imprisonment in local

Table 1: Predictive qualities of tested models on ex-post (out-of-sample predictions).

Neurons	Network optimization	RBF network		Hybrid neural network	
		MSE	stdev	MSE	stdev
3	Backpropagation	0.0000282628	0.0000129939	0.0000169513	0.0000039062
	K-means + backpropagation	0.0000175381	0.0000006224	0.0000137675	0.0000009931
	Genetic algorithm	0.0000180929	0.0000016469	0.0000136146	0.0000003816
4	Backpropagation	0.0000183763	0.0000028765	0.0000136485	0.0000005710
	K-means + backpropagation	0.0000173006	0.0000004025	0.0000130549	0.0000003013
	Genetic algorithm	0.0000176860	0.0000006219	0.0000137306	0.0000010974
5	Backpropagation	0.0000299369	0.0000812952	0.0000168334	0.0000069884
	K-means + backpropagation	0.0000174326	0.0000007575	0.0000133526	0.0000003885
	Genetic algorithm	0.0000176925	0.0000016246	0.0000141386	0.0000011016
6	Backpropagation	0.0000248756	0.0000105719	0.0000140990	0.0000016518
	K-means + backpropagation	0.0000187115	0.0000024836	0.0000140002	0.0000011530
	Genetic algorithm	0.0000205995	0.0000073265	0.0000139753	0.0000010496
7	Backpropagation	0.000029955	0.0000381995	0.0000152401	0.0000018918
	K-means + backpropagation	0.0000170959	0.0000002617	0.0000135883	0.0000004315
	Genetic algorithm	0.0000265817	0.0000100553	0.0000160908	0.0000033735
8	Backpropagation	0.0000530843	0.0000462909	0.0000161911	0.0000018501
	K-means + backpropagation	0.0000169521	0.0000003200	0.0000133422	0.0000002243
	Genetic algorithm	0.0000181709	0.0000016133	0.0000152679	0.0000030365
9	Backpropagation	0.0000594814	0.0000611668	0.0000156977	0.0000018874
	K-means + backpropagation	0.0000168649	0.0000002319	0.0000132936	0.0000003833
	Genetic algorithm	0.0000290958	0.0000136948	0.0000174571	0.0000049429
10	Backpropagation	0.0000842809	0.0000580551	0.0000163252	0.0000019133
	K-means + backpropagation	0.0000179805	0.0000029834	0.0000139659	0.0000011918
	Genetic algorithm	0.0000236821	0.0000093964	0.0000193432	0.0000056131

stdev: standard deviation.

minimum is quite possible. Another drawback to backpropagation is the "scaling problem." Backpropagation works well on simple training problems. However, as the problem complexity increases (due to increased dimensionality and/or greater complexity of the data), the performance of backpropagation falls off rapidly.

Due to these disadvantages of BP, we tested other methods for network adaptation. No surprise that the RBF network combined with K-means or GA for weights adaptation provided significantly better results than the original RBF (see Table 1). Moreover, besides lower mean MSE, another advantage of using genetic algorithm or K-means upgrade is the consistency of predictions, that is, standard deviation of performed experiments at the same network configuration (see Figure 2). The standard deviation of these methods is uncomparably lower than the standard deviation when using the standard backpropagation (see Table 1 and Figure 2).

The biggest strength of K-means is the speed of convergence of the network. Without K-means, it took considerably longer time to achieve the minimum. However, when the K-means was used to set the weights of the network before backpropagation, the time for reaching the minimum was much shorter. The advantage of this combination is that lower number of epochs is supposed to be used for network training. Moreover, K-means is quite simple to implement. However, one must bear in mind that K-means is a relatively efficient algorithm only in the domain of nonextreme values.

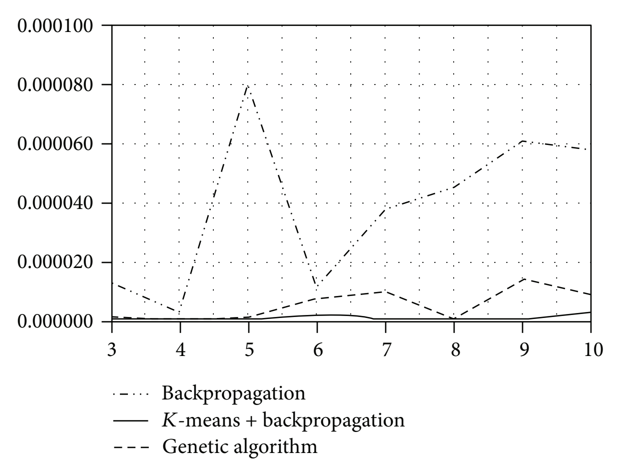


Figure 2: Standard deviation of the standard RBF network, AR(1) input.

We tested also GA in weights adaptation and we found out that the convergence is also considerably faster than at backpropagation and therefore it is no surprise that sometimes the network converged only after 5 generations. In addition to that, genetic algorithm does not have the same problem with scaling as backpropagation. One reason for this is that it generally improves the current best candidate monotonically. It does this by keeping the current best individual as part of their population while they search for better candidates. Genetic algorithms are generally not bothered by local minima. Also, genetic algorithms are especially capable of handling problems in which the objective function is discontinuous or nondifferentiable, nonconvex, multimodal, or noisy. Since the algorithms operate on a population instead of a single point in the search space, they climb many peaks in parallel and therefore reduce the probability of finding local minima. In other words, a key concept for genetic algorithms is the schemata. A schema is a subset of the fields of a chromosome set to particular values with the other fields left to vary. Therefore, as originally observed in Holland [31], the power of genetic algorithms lies in their ability to implicitly evaluate large numbers of schemata simultaneously and to combine smaller schemata into larger schemata [29]. The disadvantage of using genetic algorithms in the neural network is the fact that it demands quite a lot of parameters to set it up correctly (population size, mutation rate, crossover function, crossover rate, tournament size, fitness function, etc.).

When comparing weights adaptation via GA and K-means plus backpropagation, the results are almost the same. Even though K-means provided better results compared to GA, the differences are not very large. However, GA has a bigger potential to perform even better forecasts as there are more parameters needed to be optimized. Backpropagation, even though it is used with K-means, seemed to reach its global minimum even with the higher number of epochs (we tested backpropagation up to 10000 cycles) and the results were almost the same.

For assessing our new hybrid neural network model we used the same strategy as for the standard ANN. For the value of parameter of the moving average, we tested the values from one to one hundred and we experimentally found out the best value for the tested data (for the majority of testing procedures the optimal value of moving average parameter was 44). Finally, just like for the standard RBF, from the best ten out of twelve experiments, the mean and standard deviations of the best results of suggested hybrid (having the optimal value of MA parameter) were counted. For every number of hidden neurons tested, the results are stated in Table 1 which contains the results of out-of-sample predictions provided by the different models and optimization techniques, respectively. The illustrated results from one testing procedure are shown in Table 2 (it is important to note that the final results presented in Table 1 are made as the mean and standard deviation of ten procedures like the one in Table 2).

We also performed the predictive comparison with standard RBF network as well as the statistical ARIMA and GARCH model in order to show the prediction power of our suggested model. Table 4 states the final results of the numerical comparison of tested models. The standard RBF provided the best outputs when combined with K-means

Table 2: Prediction power of suggested hybrid model (backpropagation, one input).

MA order	MSE
0 (standard RBF)	$1.873950157362012E-5$
1	$3.799165246508804E-5$
2	$2.615127248199574E-5$
3	$2.367687507828842E-5$
4	$2.2783554024814407E-5$
5	$2.0696629830254916E-5$
6	$2.005212457137589E-5$
7	$1.9699739236710283E-5$
8	$1.899554614297672E-5$
9	$1.8775515147039734E-5$
10	$1.887215699290597E-5$
11	$1.902577681032068E-5$
12	$1.8665433411401154E-5$
13	$1.8538236785067435E-5$
14	$1.8747363637004875E-5$
15	$1.877614881966081E-5$
16	$1.885927703360986E-5$
17	$1.8730311643222403E-5$
18	$1.865192824881276E-5$
19	$1.8613846327275632E-5$
20	$1.8246180732788623E-5$
21	$1.8304204212300793E-5$
22	$1.8346810489111456E-5$
23	$1.8767301251545768E-5$
24	$1.8221445314293524E-5$
25	$1.8337288088681414E-5$
26	$1.8372328768988E-5$
27	$1.713290433035233E-5$
28	$1.7387905538550667E-5$
29	$1.7455556353006092E-5$
30	$1.76365575048565E-5$
31	$1.7430582353411663E-5$
32	$1.7628308525319124E-5$
33	$1.7295489520120636E-5$
34	$1.75881015020376E-5$
35	$1.7826153183101944E-5$
36	$1.71971230137477E-5$
37	$1.733159545759489E-5$
38	$1.6866625811781463E-5$
39	$1.668511605555683E-5$
40	$1.686512816301278E-5$
41	$1.6615393182238008E-5$
42	$1.674994621240823E-5$
43	$1.6412484212686543E-5$
44	$1.3700534874132779E-5$
45	$1.3759565540757362E-5$
46	$1.3741032598505082E-5$
47	$1.3991779046903492E-5$
48	$1.4203358839945669E-5$
49	$1.4122256244441945E-5$

Table 2: Continued.

MA order	MSE
50	$1.428843656456151E-5$
51	$1.4470021893018167E-5$
52	$1.4604793623824943E-5$
53	$1.4639288195772851E-5$
54	$1.460226532797794E-5$
55	$1.4861518152409294E-5$
56	$1.5056461844185913E-5$
57	$1.5072953046357367E-5$
58	$1.5151285670421108E-5$
59	$1.5147537079794747E-5$
60	$1.5206339461136763E-5$
61	$1.5288938970910543E-5$
62	$1.4741449702485418E-5$
63	$1.447140949098859E-5$
64	$1.4028230686891647E-5$
65	$1.4262672084968514E-5$
66	$1.4502514602499232E-5$
67	$1.4728307701510205E-5$
68	$1.4835695748235584E-5$
69	$1.4287605837827516E-5$
70	$1.4434608041518276E-5$
71	$1.4617126171765766E-5$
72	$1.4774475331564346E-5$
73	$1.4997263039128846E-5$
74	$1.5193999176213864E-5$
75	$1.544098134602122E-5$
76	$1.57116180097447E-5$
77	$1.5950812116676206E-5$
78	$1.6008865129767365E-5$
79	$1.6154963269190848E-5$
80	$1.6559218782739425E-5$
81	$1.6752087063271413E-5$
82	$1.7033959952437373E-5$
83	$1.728771469799143E-5$
84	$1.7564517921074768E-5$
85	$1.7999075641112577E-5$
86	$1.8132849402923305E-5$
87	$1.8505092071315046E-5$
88	$1.8708573514251417E-5$
89	$1.8257784663164733E-5$
90	$1.876741789470096E-5$
91	$1.920441883415449E-5$
92	$1.9082305553032882E-5$
93	$1.7957378257703227E-5$
94	$1.7963241034075204E-5$
95	$1.836522209620149E-5$
96	$1.8497275566932963E-5$
97	$1.8523003590569908E-5$
98	$1.7409426007853883E-5$
99	$1.738247641932898E-5$
100	$1.6890004735804907E-5$

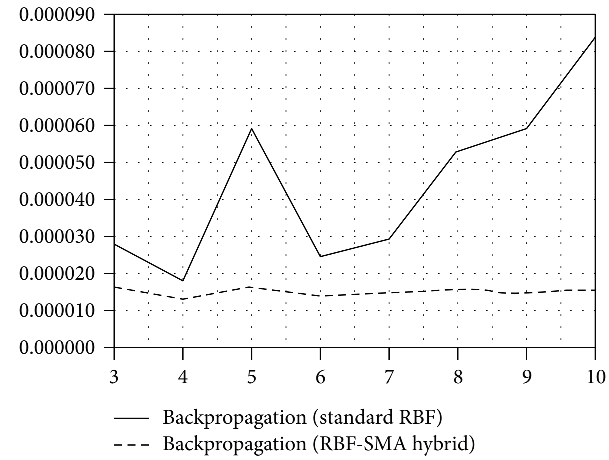


Figure 3: Predictive accuracy of standard RBF model and RBF-MA hybrid model (BP algorithm).

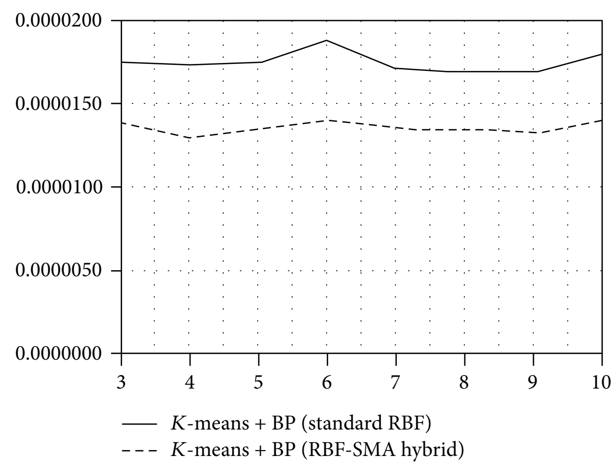


Figure 4: Predictive accuracy of standard RBF model and RBF-MA hybrid model (K-means + BP).

and backpropagation algorithms. The error of prediction at this network was a little bit lower compared to statistical model; however, these two models provided almost the same results. Nonetheless, the suggested hybrid neural network model provided much better forecasts compared to these two models. Comparing the numerical (see Table 3) as well as graphical results (see Figures 3, 4, and 5), the hybrid improved the prediction power of the standard RBF considerably. We can state that the application of our suggested new hybrid neural network model into the domain of exchange rates provides significantly better results than the standard RBF neural network as well as statistical models.

6. Conclusion

Quantitative methods are excellent tool in decision-making process as they rely on facts, numbers, and accurate mathematical methods and models. The most used approach, which has been used for many years, is a statistical approach. Statistical methods are verified methods which have been

Table 3: Percentual improvement of MSE of our hybrid model compared to the standard neural network.

Neurons	Backpropagation	K-means + backpropagation	Genetic algorithm
3	40,022573	21,499478	24,751698
4	25,727704	24,540767	22,364582
5	43,770397	23,404426	20,087043
6	43,321970	25,178633	32,157091
7	49,123352	20,517200	39,466626
8	69,499268	21,294707	15,976094
9	73,609061	21,175933	40,001306
10	80,630012	22,327521	18,321433

Table 4: Predictive comparison of tested models, best configurations (ex-post).

Model	Regressor(s)	Weights adaptation	MSE*1	sd*2
RBF	Autoregressive (1)	Backpropagation	0.0000183763	0.0000028765
		K-means + backpropagation	0.0000168649	0.0000002319
		Genetic algorithm	0.0000176860	0.0000006219
RBF-SMA	Autoregressive (1)	Back-Propagation	0.0000136485	0.0000005710
		K-means + backpropagation	0.0000130549	0.0000003013
		Genetic algorithm	0.0000136146	0.0000003816
AR(0)-EGARCH(1,1,1)	Conditional variance (1)	Marquardt	0.0000170651	—
		Berndt-Hall-Hall-Hausman	0.0000170651	—

*1: mean squared error; *2: standard deviation.

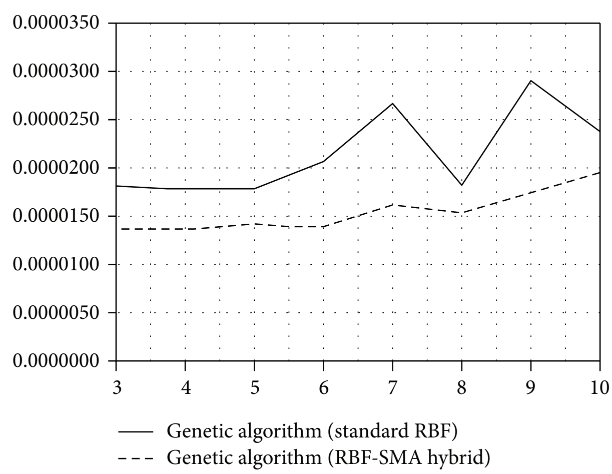
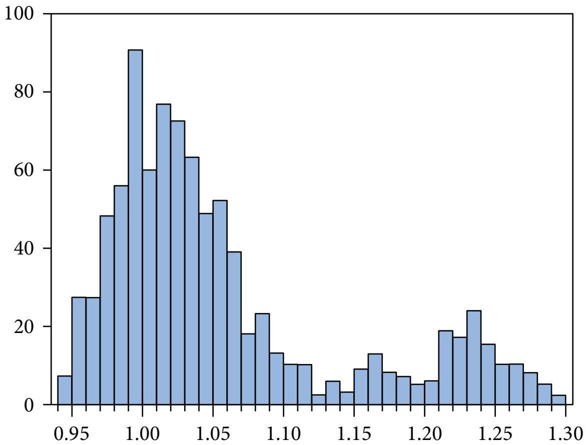


Figure 5: Predictive accuracy of standard RBF model and RBF-MA hybrid model (genetic algorithm).

used in forecasting process for many years. As for computing intelligent technologies, they are getting more and more popular nowadays. The main representative neural networks are based on mathematical model of human neuron and therefore it does not have to fulfil any initial assumptions like statistical models. In this paper we tested the predictive power of neural networks in the domain of exchange rates. We suggested a new hybrid network model combined with moving averages. We used USD/CAD data which was later divided into training set and validation due to model checking. We also performed the tests with the statistical model. We also used other algorithms in the neural network training process; we combined RBF with an unsupervised learning method called K-means and GA into the RBF. The reason for incorporating other algorithms into the network was that the BP is considered a weakness of the RBF. Both of these upgrades showed to be helpful in the process of creating better forecasts and should be definitely used instead of the standard BP.

By performing experiments we can deduce that the models of ANN are relatively fast, they are able to generalize, and in addition to that it is not necessary to know all the relationships of the system. Thanks to that, ANN modeling is enabled to people who are not able to identify relations between the variables of the model by using Box-Jenkins, GARCH, or any other methodology. Moreover, in this work we also suggested a new hybrid neural network model. The reason for this was to improve the prediction accuracy of our customized standard neural network. As for the prediction results of our hybrid, we performed experiments to find out that our suggested RBF-MA hybrid neural network has a significant predictive superiority over the statistical model as well as standard neural network models. On the validation set the tested hybrid model proved excellent results and according to MSE errors on the validation set, it was by far the best model of all tested models. In our experiments its numerical characteristics always overcame individual models (ANN, statistical model); the improvements ranged from



Series: USD_CAD
Sample 10/31/2008–4/30/2012
Observations 912

Mean	1.056452
Median	1.028450
Maximum	1.296300
Minimum	0.942800
stdev	0.085466
Skewness	1.217163
Kurtosis	3.415412
Jarque-Bera	231.7433
Probability	0.000000

Figure 6: Histogram and statistical characteristics of original series of USD/CAD (training set).

about 18 per cent to more than 89 per cent. Our hybrid neural network model showed to be a great improvement of the standard RBF neural network as we experimentally clearly proved that for the USD/CAD this hybrid model provided significantly better forecasts than the standard model of the RBF neural network and as the statistical model and hence there was a clear benefit of better one-day-ahead forecasts.

Despite the fact that neural networks and soft computing techniques are a minor approach used in decision process of business forecasting, it is definitely an attractive alternative to traditional statistical models. Moreover, following from our empirical findings for out-of-sample one-step-ahead forecasts, we believe that our suggested hybrid model has also a great potential in the whole domain of financial forecasting as well as other areas of continuous forecasting.

Appendix

Box-Jenkins Statistical Modeling

The empirical Box-Jenkins analysis [37] focuses on the original and differentiated series of daily observations of USD/CAD currency pair covering a historical period from October 31, 2008, to October 31, 2012. The reason for this particular study was to perform a comparison between our tested model and the standard statistical model. The data, as stated above, was downloaded from the following website: http://www.global-view.com/forex-trading-tools/forex-history/, and the statistical characteristics are in Figure 6.

As stated in the previous part of this paper, data was divided into two parts—the training part and validation part. As the validation part was used for model checking, we only used observations from training set for statistical modeling. For statistical modeling which included model identification, model quantification, and model validation, the Eviews software was used. Some of the advantages of this software include simplicity, user friendliness, or detailed outputs. In addition to that, it also has various versions of GARCH model implemented.

Unit root tests results [39–42] presented in Table 5 show that this series is not stationary as it is characterized by a unit root. In order to stationarize the series, it was differentiated. As seen from Table 5, unit root tests confirmed that the differentiated series was stationary which is a necessary condition in Box-Jenkins modeling.

By analyzing autocorrelation (ACF) and partial autocorrelation function (PACF) of the differentiated series of USD/CAD (see Figure 8), there were no significant correlation coefficients, so one could deduce that first differences of the original series formed a white noise process. In that case, the original series would have formed random walk process (RWP) as RWP was $I(1)$ process. Assuming the returns of the original series formed a random walk process, we selected AR(0) as the basic level model. Ljung-Box Q-statistics confirmed this assumption and the applicability of AR(0) process as the correlations were statistically not significant.

However, the assumption of normality of residuals of AR(0) returns was rejected (see Table 6). Moreover, the observed asymmetry might have indicated the presence of nonlinearities in the evolution process of returns. This nonlinearity was confirmed by graphical quantiles comparison (versus normal distribution) and a scatter plot of the series which did not appear to be in the form of a regular ellipsoid (see Figures 9 and 10). In addition, BDS test rejected the random walk hypothesis (see Table 7) as the BDS statistic is greater than the critical value at 5%. Therefore, other tests had to be performed in order to correctly model this series.

We noted that the residuals (Figure 11) were not characterized by a Gaussian distribution (see Table 6). The asymmetry might have indicated nonlinearities in the residuals. When looking at the graph of residuals (Figure 11) one could observe that the variability of these residuals could be caused by a nonconstant variance. Residual with small value follows another residual with a small value. On the other hand, residual with a large value usually follows a residual with another large value. However, this was not typical for a white noise process. This assumption leads us to think about stochastic model for volatility. The suitability for using stochastic volatility model was also accepted by performing heteroskedasticity test. ARCH test (see Table 6) confirmed

Table 5: Unit root tests of USD/CAD.

(a)

Test		Original series [p value]		1st differences (returns) [p value]
Augmented Dickey-Fuller	(I)	−1.017396 [0.2781]	(I)	−30.61353 [0.0000]
	(II)	−1.848666 [0.3569]	(II)	−30.61866 [0.0000]
	(III)	−2.454401 [0.3510]	(III)	−30.60792 [0.0000]
Phillips-Perron	(I)	−1.077154 [0.2550]	(I)	−30.66946 [0.0000]
	(II)	−1.794202 [0.3836]	(II)	−30.68702 [0.0000]
	(III)	−2.415434 [0.3712]	(III)	−30.67642 [0.0000]

(b)

Test	Window	Spectral estimation method							
		Bartlett kernel				Quadratic spectral kernel			
		Original series		Returns		Original series		Returns	
		(II)	(III)	(II)	(III)	(II)	(III)	(II)	(III)
KPSS H_0: stationary series	Newey-West	2.735123 (0.463)	0.668131 (0.146)	0.074401 (0.463)	0.026211 (0.146)	4.846899 (0.463)	1.158977 (0.146)	0.072329 (0.463)	0.025495 (0.146)
	Andrews	0.380551 (0.463)	0.150720 (0.146)	0.065257 (0.463)	0.022956 (0.146)	0.306275 (0.463)	0.132197 (0.146)	0.065106 (0.463)	0.022906 (0.146)
Elliot-Rothenberg-Stock H_0: unit root	Newey-West	30.18086 (3.26)	8.632243 (5.62)	0.358755 (3.26)	0.438046 (5.62)	29.71523 (3.26)	8.977311 (5.62)	0.352926 (3.26)	0.431096 (5.62)
	Andrews	27.06265 (3.26)	8.375229 (5.62)	0.323259 (3.26)	0.394417 (5.62)	27.29972 (3.26)	8.378941 (5.62)	0.323530 (3.26)	0.394799 (5.62)

(I): model without constant and deterministic trend (5%).
(II): model with constant and without deterministic trend (5%).
(III): model with constant and deterministic trend (5%).

Table 6: Normality tests on distribution of residuals and other main characteristics.

Skewness	Kurtosis	J.B.	A.D.	ARCH-LM statistic
0.168931	5.518599	245.1157 [0.0000]	6.422445 [0.0000]	139.4994 [0.0000]

J.B.: Jarque-Bera statistic and A.D.: Anderson-Darling statistic.

that the series was heteroskedastic since the null hypothesis of homoscedasticity was rejected at 5% and so the residuals were characterized by the presence of ARCH effect which is quite a frequent phenomenon at financial time series. Therefore, we applied a stochastic volatility model into the basic model.

We estimated several models of ARCH [43] and GARCH [1], respectively. We estimated several stochastic models; except for the basic GARCH model we estimated GARCH extensions too. For modelling the ARCH model we used the information from the correlogram of squared residuals (Figure 12). For each model we calculated Akaike [44], Schwarz [45] information criteria, and log-likelihood function. It is important to remember that the estimation of different models was only based on 912 in-sample observations, in order to make ex-ante predictions with remaining 132 observations. We used Marquardt optimization procedure for finding the optimal values of GARCH parameters; initial values of parameters were counted using Ordinary Least Squares (OLS) method and then these values by iterative process consisted of 500 iterations. Convergence rate was set to 0.0001.

In view of Table 8, we find that the information criteria are minimum for GARCH$(1, 1)$ model with GED error distribution. It showed that GARCH$(1, 1)$ is very well applied for this type of time series as well as other financial time series. Regarding the fact that we applied the models on exchange rate data, it was no surprise that the asymmetrical effect was not present. The residuals of the models were characterized by the absence of conditional heteroskedasticity: the ARCH-LM statistics are strictly less than the critical value at 5%. In addition, the standardized residuals tested with Ljung-Box Q test confirmed that there were no significant coefficients

Table 7: BDS test results on the series of AR(0) residuals.

m	Fraction of pairs		sd	
	BDS statistic	z-statistic [p value]	BDS statistic	z-statistic [p value]
2	0.010940	3.729713 [0.0000]	0.007757	3.545123 [0.0000]
3	0.028568	6.150556 [0.0000]	0.013889	6.456223 [0.0000]
4	0.044991	8.162869 [0.0000]	0.014137	8.905923 [0.0000]
5	0.055748	9.738419 [0.0000]	0.011450	11.16068 [0.0000]
6	0.062941	11.44079 [0.0000]	0.008584	13.98217 [0.0000]
7	0.066187	13.17452 [0.0000]	0.006155	17.62420 [0.0000]
8	0.066580	15.04687 [0.0000]	0.004189	21.85108 [0.0000]
9	0.065576	17.28602 [0.0000]	0.002799	27.30739 [0.0000]
10	0.062153	19.51334 [0.0000]	0.001781	33.16601 [0.0000]

The BDS statistic was computed by two methods, with $\varepsilon = 0.7$.

Table 8: Evaluation characteristics of tested models.

Model	Error distribution	Akaike	Schwarz	Log-likelihood
ARCH(5)	Gaussian	−6.946032	−6.909037	317.917
	Student	−6.966257	−6.923978	3181.130
	GED	−6.967443	−6.925164	3181.670
ARCH(7)	Gaussian	−6.970504	−6.922940	3184.065
	Student	−6.984941	−6.932092	3191.641
	GED	−6.985553	−6.932704	3191.919
GARCH(1,1)	Gaussian	−7.029560	−7.008420	3205.964
	Student	−7.032833	−7.006409	3208.456
	GED	−7.034504	−7.008779	3209.216
EGARCH(1,1,1)	Gaussian	−7.025497	−6.999073	3205.114
	Student	−7.028507	−6.996797	3207.485
	GED	−7.030426	−6.998717	3208.359
PGARCH(1,1,1)	Gaussian	−7.026622	−6.994912	3206.626
	Student	−7.029612	−6.992618	3208.988
	GED	−7.031268	−6.994274	3209.743
TGARCH(1,1,1)	Gaussian	−7.028705	−7.002281	3206.575
	Student	−7.031598	−6.999888	3208.893
	GED	−7.033244	−7.001535	3209.643

GED: generalized error.

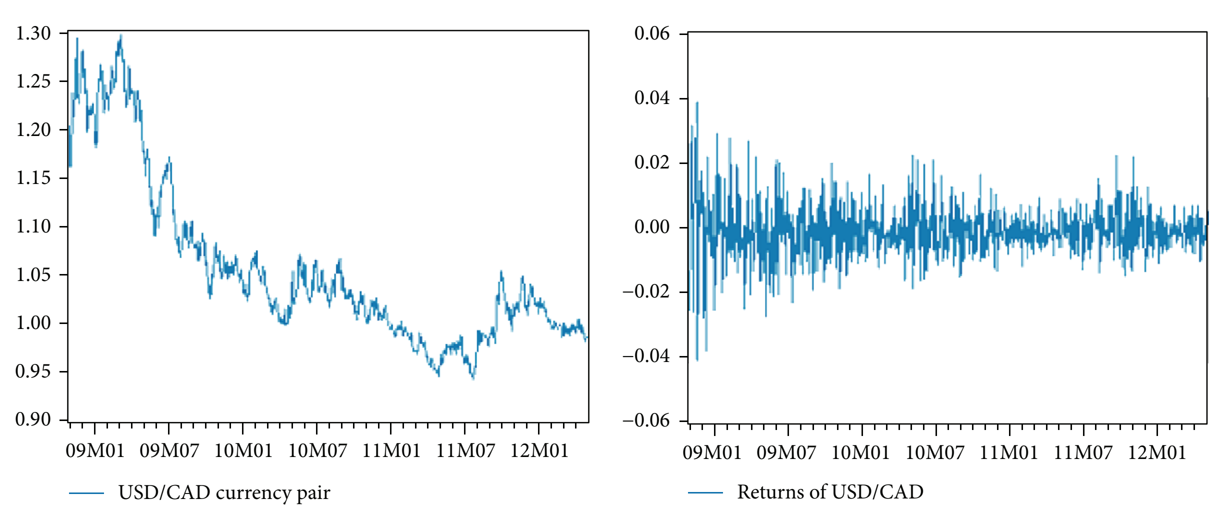


Figure 7: USD/CAD (original series and differences of the original series).

Autocorrelation	Partial correlation		AC	PAC	Q-statistic	Probability
		1	−0.014	−0.014	0.1798	0.672
		2	−0.010	−0.010	0.2714	0.873
		3	−0.039	−0.040	1.6846	0.640
		4	−0.012	−0.013	1.8116	0.770
		5	−0.072	−0.073	6.5686	0.255
		6	0.056	0.052	9.4618	0.149
		7	−0.036	−0.038	10.653	0.154
		8	−0.038	−0.044	11.989	0.152
		9	−0.048	−0.048	14.090	0.119
		10	−0.034	−0.044	15.180	0.126

Figure 8: ACF and PACF of USD/CAD returns.

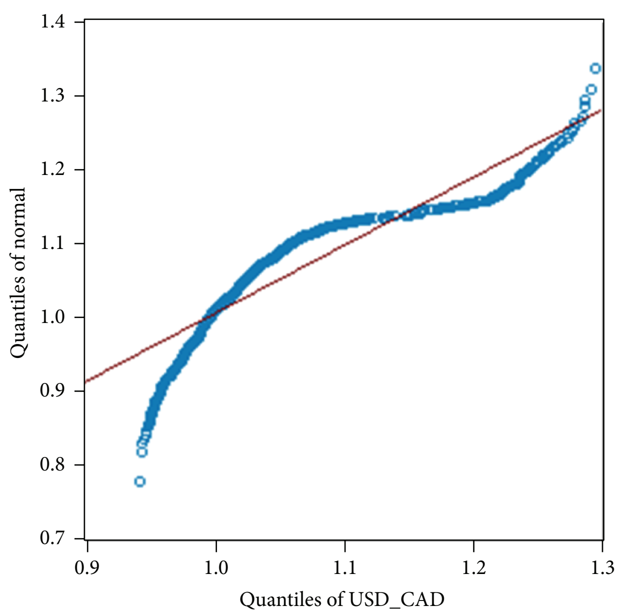


Figure 9: Quantiles of USD/CAD residuals versus the normal distribution quantiles.

Table 9: Comparison of predictive qualities (out-of-sample predictions, 1-day horizon).

Model	Error distribution	MSE	MAPE
AR(0)-ARCH(5)	Gaussian	0.00001709	0.319356
	Student	0.00001720	0.320744
	GED	0.00001718	0.320459
AR(0)-ARCH(7)	Gaussian	0.00001708	0.319096
	Student	0.00001717	0.320443
	GED	0.00001714	0.320122
AR(0)-GARCH(1,1)	Gaussian	0.00001709	0.319374
	Student	0.00001715	0.320223
	GED	0.00001714	0.320117
AR(0)-EGARCH(1,1,1)	Gaussian	0.00001706	0.318886
	Student	0.00001714	0.320108
	GED	0.00001711	0.319692
AR(0)-PGARCH(1,1,1)	Gaussian	0.00001706	0.318916
	Student	0.00001711	0.319660
	GED	0.00001712	0.319719
AR(0)-TGARCH(1,1,1)	Gaussian	0.00001706	0.318897
	Student	0.00001712	0.319767
	GED	0.00001712	0.319699

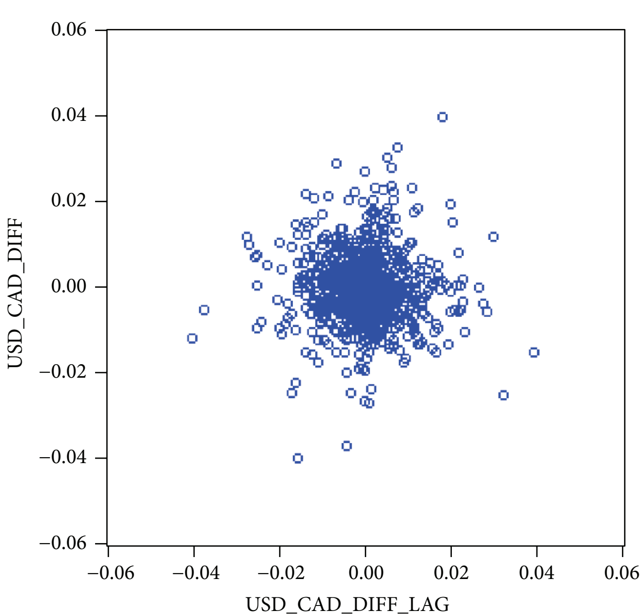


Figure 10: Scatter plot of USD/CAD residuals variations.

in residuals of these models. Figure 13 states these results for GARCH(1, 1) GED model.

To compare the forecasting performance of the tested models two criteria were used: the mean squared error (MSE) and the mean absolute percentage error (MAPE). We primarily tested the forecasting accuracy on the validation set, that is, out-of-sample predictions, and we used one-step-ahead predictions.

The best results for out-of-sample prediction were achieved with EGARCH(1, 1, 1) model with Gaussian error distribution (Table 9). Therefore, this model will be later compared with the neural network models and our suggested model. This volatility is defined as follows:

$$\log(h_t) = -0.172109 + 0.117148\frac{|\varepsilon_{t-1}|}{\sqrt{h_t}} + 0.037398\frac{|\varepsilon_{t-1}|}{\sqrt{h_t}} + 0.992135\log(h_{t-1}). \tag{A.1}$$

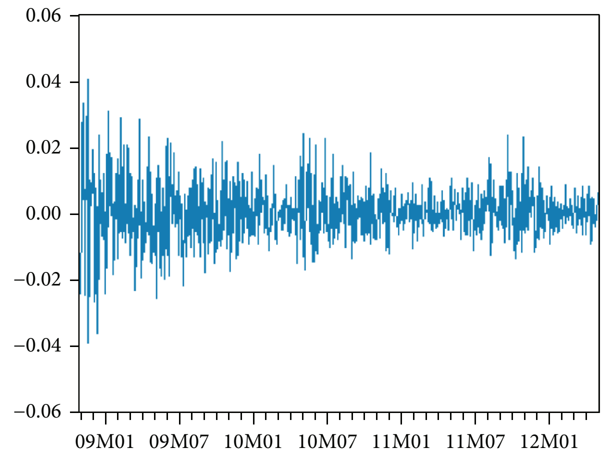


Figure 11: Evolution of residuals.

Autocorrelation		AC	Q-statistic	Probability
	1	0.096	8.4277	0.004
	2	0.220	52.850	0.000
	3	0.186	84.531	0.000
	4	0.094	92.714	0.000
	5	0.169	118.89	0.000
	6	0.236	170.00	0.000
	7	0.118	182.92	0.000
	8	0.212	224.24	0.000
	9	0.050	226.57	0.000
	10	0.208	266.42	0.000

Figure 12: Correlogram of squared residuals.

Autocorrelation	Partial correlation		AC	PAC	Q-statistic	Probability
		1	−0.033	−0.033	0.9663	0.326
		2	−0.007	−0.008	1.0087	0.604
		3	−0.025	−0.026	1.5847	0.663
		4	−0.041	−0.043	3.1585	0.532
		5	−0.051	−0.055	5.5879	0.348
		6	0.053	0.049	8.2029	0.224
		7	−0.010	−0.009	8.2864	0.308
		8	−0.004	−0.008	8.2992	0.405
		9	−0.058	−0.061	11.361	0.252
		10	−0.047	−0.051	13.413	0.202

Figure 13: ACF and PACF of AR(0)-GARCH(1, 1) GED residuals.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Application of Artificial Intelligence for Bridge Deterioration Model

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The deterministic bridge deterioration model updating problem is well established in bridge management, while the traditional methods and approaches for this problem require manual intervention. An artificial-intelligence-based approach was presented to self-updated parameters of the bridge deterioration model in this paper. When new information and data are collected, a posterior distribution was constructed to describe the integrated result of historical information and the new gained information according to Bayesian theorem, which was used to update model parameters. This AI-based approach is applied to the case of updating parameters of bridge deterioration model, which is the data collected from bridges of 12 districts in Shanghai from 2004 to 2013, and the results showed that it is an accurate, effective, and satisfactory approach to deal with the problem of the parameter updating without manual intervention.

1. Introduction

In bridge management, many problems, especially in bridge deterioration model, were influenced by uncertainties which not only could be solved in need of mathematics and mechanics calculations but also depend on the knowledge and experience of experts [1, 2]. The most interesting condition of the bridge is the performance, which is evaluated by studying the functional or structural behavior of the bridge. Bridge deterioration model is one of the key elements of bridge performance, which can be used to analyze bridge life-cycle costs and estimate the type and timing of bridge maintenance and rehabilitation needs. In these models, the dependent variable of observed or measured structural or functional deterioration is related to a set of independent variables. There are two broad categories of models available in the literature: deterministic models and probabilistic models. Deterministic models estimate the average value of the dependent variable (such as the remaining life of a bridge or its level of distress). Most deterministic models used in bridge deterioration model are based on regression analysis [3–5]. Probabilistic models estimate a range (or distribution) of values for a dependent variable. Most probabilistic models used in bridge deterioration model are based on Markovian theory [6–8].

Bridge deterioration model, especially deterministic models, need to update the parameter constantly when new data is collected. The conventional regressive analysis would consume a large number of computation time and computing resources. What is more, it relies heavily on the manual intervention in bridge management. However, artificial intelligence has its own superiority. It can solve this problem by means of imitate human intelligence.

Artificial intelligence (AI) is generally considered to be a subfield of computer science that is concerned to attempt simulation, extension, and expansion of human intelligence [9, 10]. It was developed based on the interaction of several kinds of disciplines, such as computer science, cybernetics, information theory, psychology, linguistics, and neurophysiology [11]. The goal of this field is to explore how to imitate and execute some of the intelligence functions of human brain, so that people can develop technology products and establish relevant theories [12, 13]. The nominal birth of AI is considered to have occurred at a conference held at Dartmouth College in the summer of 1956. After that, AI has been a far-reaching cross-frontier subject. Its tools and techniques are in the mainstream of computer science and at the core of so many systems, such as expert system, intelligence database system, and knowledge base system. We have made significant headway in solving fundamental problems in representing knowledge, reasoning, machine learning, and more, and a lot of hopes and dreams about it have been generated [14–18]. Artificial intelligence has also been widely applied to update model parameters. Corchado and Aiken [19] presents the application of a novel hybrid artificial-intelligence model to a real time forecasting problem, which provided an effective strategy for forecasting in an environment in which the raw data is derived from three distinct sources. Amayri and Bouguila [20] proposed a principled statistical framework that simultaneously determines relevant features, number of clusters while being able to incrementally update model's parameters. Mishra [21] used H_∞-learning method for updating the parameter of the radial basis function neural network to improve the transient stability performance of a multimachine power system. Khodaparast et al. [22] adapted a similar method and proposed two perturbation based methods to determine the first and the second statistical moments of updating parameters. They investigated the influence of correlation between the updated and the modal parameters on the results of a 3-degree-of-freedom simple system and truss structure. Moaveni et al. [23] presented a study in order to quantify and analyze uncertainties in damage detection problem using finite element model updating strategy. They perform a gradient based optimization method to minimize the objective function which includes the residuals of experimental and numerical modal parameters for different combinations of uncertainty source. Singhal and Kiremidjian [24] used Bayesian analysis method for updating earthquake ground motion by damage relationships and for estimating confidence bounds when building damage information from historical earthquakes becomes increasingly available. Enright and Frangopol [25] applied Bayesian method updating to condition prediction of deteriorating concrete bridge, which combined the information both from inspection result and from engineering judgment, and this developed approach was illustrated for a reinforced bridge. Strauss et al. [26] proposed a Bayesian approach for updating prediction functions, which incorporated past data and information. Ching and Leu [27] proposed a Bayesian algorithm to quickly update the reliability of the infrastructure system according to the timely condition data, and this method was demonstrated with a real-world case of hydraulic spillway gate system. Wang et al. [28] developed a Bayesian approach for updating a model for predicting excavation settlement using centrifuge test information, and the results of case study showed that the accuracy can be improved.

An artificial-intelligence-based approach (AI-based approach) for updating deterministic model parameters of bridge deterioration model is researched in this paper. From the above literatures, it can conclude that the characteristics of Bayesian theorem are well suited for updating models, while the process of model updating cannot work without manual intervention. For this problem, an AI-based approach for updating deterministic model parameters is proposed by using Bayesian theorem in this paper, which imitate some of intelligence function of human brain and realize the self-updating parameters of bridge deterioration model.

In the first section, we overview the bridge deterioration model and artificial intelligence, especially Bayesian theorem. In Section 2, the framework of AI-based approach for updating parameters is founded, and then the mechanism of AI-based approach for updating parameters is proposed, which is the core of AI-based approach for updating parameters and can be applied to realize the parameter self-updating of bridge deterioration model. In Section 3, a case study about bridge deterioration model is illustrated for the process of the AI-based approach for updating parameters. We then summarize the proposed AI-approach in Section 4.

2. AI-Based Approach

2.1. The Framework of AI-Based Approach for Updating Parameters. AI-based approach for updating parameters allows bridge deterioration model to self-update parameters when new information or data is collected using Bayesian theorem. Mathematically, the Bayesian theorem can be expressed as follows:

$$p(\alpha_1 \mid \alpha_2) = \frac{f(\alpha_2 \mid \alpha_1)\,\pi(\alpha_1)}{\int_\Theta f(\alpha_2 \mid \alpha_1)\,\pi(\alpha_1)\,d\alpha_1}, \qquad (1)$$

where $\pi(\alpha_1)$ is the prior distribution of model parameters, which describes the historical information and data before any new information or data of α_2 is obtained. In other words, $\pi(\alpha_1)$ represents the initial parameters, and it is acceptable to a skeptical scientific audience. $f(\alpha_2 \mid \alpha_1)$ is the likelihood function, which describes the sampling results about any new information or data of α_2. $p(\alpha_1 \mid \alpha_2)$ is the posterior distribution, which describes the integrated result of historical information $\pi(\alpha_1)$ and the new information $f(\alpha_2 \mid \alpha_1)$. In fact, the resulting posterior distribution is always a compromise between the prior credibility of the parameter values and the likelihood of the random variables for the data. This compromise is increasingly controlled by the data as the sample size increases in what is sometimes referred to as asymptotic theory [29–31].

In this AI-based approach for updating parameters, the updating process can be divided into three stages. Firstly, a prior distribution should be established. A large amount of historical information and data are used to quantify as the prior distribution, namely, the initial model parameters. Secondly, a posterior distribution should be established when time series data is obtained in real-time, which includes the information of both the prior distribution and new collected data. Finally, model parameters can be updated by the posterior distribution. And Figure 1 resumes this overall updating process.

2.2. The Mechanism of AI-Based Approach for Updating Parameters. From the framework of the AI-based approach for updating parameters, the historical and new collected information and data are integrated and depicted by the posterior distribution, so it is the emphasis and difficulty of

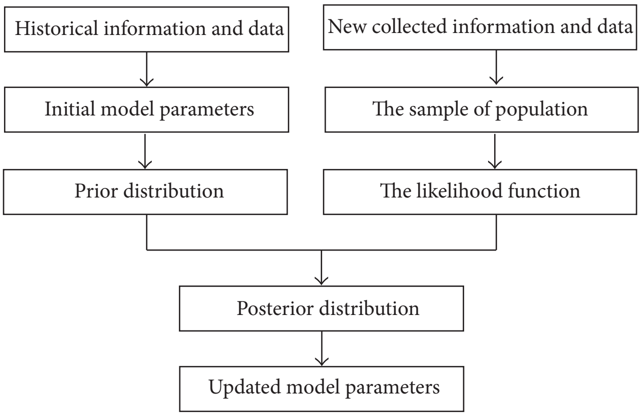

FIGURE 1: The framework of AI-based approach for updating parameters.

how to construct a posterior distribution $p(\alpha_1 \mid \alpha_2)$ based on the prior distribution $\pi(\alpha_1)$ and new collected data X as (1). In this section, the parameters of bridge deterioration model were regarded as unknown variables; namely, the mean and the variance were random unknown variables, and the derivation process from a prior distribution to a posterior distribution will be discussed in detail. When the sample size is large enough, it is reasonable that a normal distribution is used to describe the parameters of bridge deterioration model according the center limit theorem [32]. In this AI-based approach for updating parameters, the initial parameters of bridge deterioration model was set based on the historical data, the new obtained data was regarded as a sample of the population, and then we can deduce a posterior distribution about the parameters of bridge deterioration model according to the prior distribution and the sample.

Assuming that population follows a normal distribution $N(\alpha, \delta^2)$, which consists of historical data and new obtained data, the value of population parameter (α) can be gained according to the least square method. The historical data also follows a normal distribution $N(\alpha_1, \delta_1^2)$, parameter (α_1) can be gained by regressing those historical data, and it is used to quantify as the prior distribution of population parameter (α). The new collected data is regarded as a sample of the population and also follows a normal distribution $N(\alpha_2, \delta_2^2)$, and parameter (α_2) can be gained by regressing the new collected data. Before any new information and data are collected, we consider the following:

$$\begin{aligned} \delta^2(1) &= \delta_1^2, \\ \alpha(1) &= \alpha_1. \end{aligned} \tag{2}$$

According to the Bayesian theorem, a connection is constructed between the historical information and new collected information, so parameters α and δ^2 are calculated, and the formulations are given as [33]:

$$\begin{aligned} \delta^2(2) &= \frac{n_1\delta_1^2 + n_2\delta_2^2}{n_1 + n_2} + \frac{n_1 n_2}{(n_1+n_2)^2}(\alpha_1 - \alpha_2)^2 \\ &\approx \frac{n_1\delta_1^2 + n_2\delta_2^2}{n_1 + n_2}, \end{aligned} \tag{3}$$

$$\alpha(2) = \frac{\left(\alpha_1/\delta_1^2 + \alpha_2/\delta^2\right)}{\left(1/\delta_1^2 + 1/\delta^2\right)} = \frac{\alpha_1\delta^2(2) + \alpha_2\delta_1^2}{\delta^2(2) + \delta_1^2}, \tag{4}$$

where n_1 is the size of the historical data, parameters α_1 and δ_1^2 are gained by regressing the historical data, n_2 is the size of the new collected data, and parameters α_2 and δ_2^2 are gained by regressing the new collected data.

In next stage, the new data will be collected continually. In this case, this new collected data is regarded as a sample of the population, and any other information and data become historical information and data, which is descripted by the prior distribution. It is obvious that this prior distribution equals the posterior distribution at the previous stage. In other words, for (3), the size of the historical information and data should be assigned by the sum of (n_1) and (n_2). For (4), the parameter α_1 should be assigned by α. It is as follows:

$$\begin{aligned} \delta^2(3) &= \frac{n_1\delta_1^2 + n_2\delta_2^2 + n_3\delta_3^2}{n_1 + n_2 + n_3}, \\ \alpha^2(3) &= \frac{\alpha(2)\delta^2(3) + \alpha_3\delta^2(2)}{\delta^2(2) + \delta^2(3)}. \end{aligned} \tag{5}$$

From the above description and inference, the recursion formulas are constructed for updating model parameters when new information and data are gained continually. They are given as follows:

$$\delta^2(i) = \frac{n_1\delta_1^2 + n_2\delta_1^2 + \cdots + n_i\delta_i^2}{n_1 + n_2 + \cdots + n_i} = \frac{\sum_{j=1}^{i} n_j\delta_j^2}{\sum_{j=1}^{i} n_j}, \quad (i = 1, 2, 3, \ldots), \tag{6}$$

$$\alpha(i) = \begin{cases} \alpha_1, & i = 1, \\ \dfrac{\alpha(i-1)\delta^2(i) + \alpha_i\delta^2(i-1)}{\delta^2(i-1) + \delta^2(i)}, & i = 2, 3, 4, \ldots, \end{cases} \tag{7}$$

where i is the times of updating model parameters and other notations are the same as above.

According to (6) and (7), the new collected information and data are entered into parameters on the basic of the information and data gathered in the previous stage, so the model parameters can be self-updating consistently.

3. Approach Verification through Case Study

The AI-based approach for updating parameters is tested and verified through bridge deterioration model with the data collected from bridges of 12 districts in Shanghai from 2004 to 2013. The bridge deterioration model that was proposed by Chen of Tongji University in 2005 is currently adopted by bridge management agencies in Shanghai. The model form is as follows [34]:

$$\mathrm{PPI} = \mathrm{PPI}_0\left\{1 - \exp\left[-\left(\frac{\alpha}{y}\right)^{\beta}\right]\right\}, \tag{8}$$

Table 1: Regressive results of new collected data.

Year	The size of processed data	The value of parameter (α)	The value of parameter (β)	The value of δ^2
2004	124	22.0	1.09	0.390
2005	140	21.6	1.14	0.316
2006	177	23.2	0.98	0.180
2007	182	23.3	0.98	0.190
2008	188	22.4	1.00	0.102
2009	183	22.7	0.99	0.169
2010	184	23.7	0.91	0.100
2011	194	22.9	1.00	0.142
2012	171	23.0	0.97	0.116
2013	182	23.0	0.95	0.184

where PPI is the index of bridge performance, such as BCI; PPI_0 is the index of initial bridge performance; y is the age of bridge; and α and β are the model parameter. It is necessary to update α and β consistently because of the changes in the external environment and the structure of the bridge itself.

The regressive results of new collected data are listed in Table 1.

The current approach (hereafter referred to as "conventional approach") updates the parameters by regressing all data once new data is collected. For example, in 2004, the value of parameters α and β can be gained by regressing the data collected from 2004, the regressive results are $\alpha = 22.0$, $\beta = 1.09$, and the size of processed data is 124. In 2005, the value of parameters α and β is gained by regressing the data collected from 2004 to 2005, the regressive results are $\alpha = 21.7$, $\beta = 1.07$, and the size of processed data is 264, which is the sum of the size of the data collected from 2004 to 2005. On the analogy of this, in 2013, the value of parameters α and β is gained by regressing the data collected from 2004 to 2013, the regressive results are $\alpha = 22.8$, $\beta = 0.99$, and the size of processed data is 1725, which is the sum of the size of the data collected from 2004 to 2013.

The AI-based approach developed in this paper (hereafter referred to as "new approach") updates the parameters according the formulations (7) and (8). In this Approach, the model parameters can be directly calculated on the basic of the parameter of original data and the parameter of new collected data, instead of regressing the population of original data and new collected data. For example, it can be found that the value of parameter is as follows from Table 1: $\alpha_{2004} = 22.0$, $\beta_{2004} = 1.09$, $\delta^2_{2004} = 0.390$, $n_{2004} = 124$, $\alpha^1_{2005} = 21.58$, $\beta^1_{2005} = 1.14$, $\delta^{12}_{2005} = 0.316$, and $n^1_{2005} = 140$. Afterward, according formulations (7) and (8), it is easy and quickly to get the value of the parameter in 2005. The calculated process is as follows:

$$\delta^2_{2005} = \frac{n_{2004}\delta^2_{2004} + n^1_{2005}\delta^{12}_{2005}}{n_{2004} + n^1_{2005}}$$

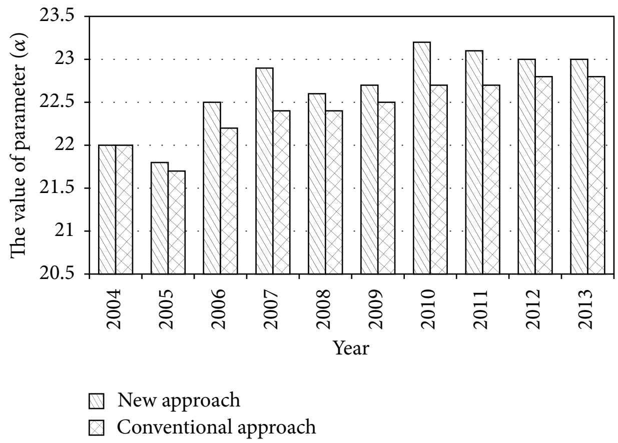

Figure 2: The value of parameter (α).

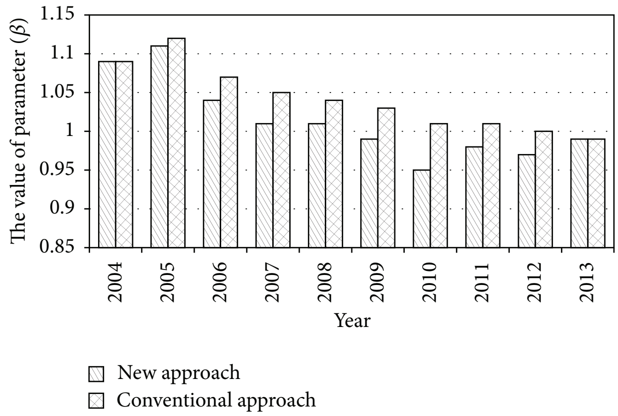

Figure 3: The value of parameter (β).

$$\begin{aligned}
&= \frac{124 \times 0.390 + 140 \times 0.316}{124 + 140} = 0.351, \\
\alpha_{2005} &= \frac{\alpha_{2004}\delta^2_{2005} + \alpha^1_{2005}\delta^2_{2004}}{\delta^2_{2005} + \delta^2_{2004}} \\
&= \frac{22.0 \times 0.351 + 21.58 \times 0.390}{0.351 + 0.390} = 21.8, \\
\beta_{2005} &= \frac{\beta_{2004}\delta^2_{2005} + \beta^1_{2005}\delta^2_{2004}}{\delta^2_{2005} + \delta^2_{2004}} \\
&= \frac{1.09 \times 0.351 + 1.14 \times 0.390}{0.351 + 0.390} = 1.12.
\end{aligned} \tag{9}$$

So, the value of parameter from 2004 to 2013 can be calculated by using this new approach. In order to compare the result of the new approach and the conventional approach, the updating results are listed in Table 2 from 2004 to 2013, and the comparison of the data in Table 2 is shown in Figures 2–4.

From the process of updating parameter, the AI-based approach for updating parameters realizes the parameter self-updating of bridge deterioration model when new data

Table 2: Results of new approach and conventional approach.

Year	The size of processed data		The value of parameter (α)		The value of parameter (β)	
	New	Conventional	New	Conventional	New	Conventional
2004	124	124	22.0	22.0	1.09	1.09
2005	140	264	21.8	21.7	1.11	1.12
2006	177	441	22.5	22.2	1.04	1.07
2007	182	623	22.9	22.4	1.01	1.05
2008	188	811	22.6	22.4	1.01	1.04
2009	183	994	22.7	22.5	0.99	1.03
2010	184	1178	23.2	22.7	0.95	1.01
2011	194	1372	23.1	22.7	0.98	1.01
2012	171	1543	23.0	22.8	0.97	1.00
2013	182	1725	23.0	22.8	0.99	0.99

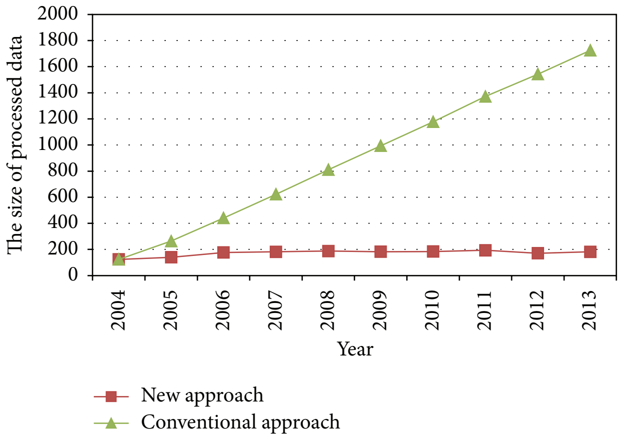

Figure 4: The size of processed data.

was collected, instead of depending on manual intervention, which is the biggest advantage of this approach. In addition, according to the case study results, it can be found that the results of new approach and conventional approach are approximately equal each year (i.e., the difference of the value of parameter α between new approach and conventional approach varies from 0 to 0.5 and the difference of the value of parameter β between new approach and conventional approach varies from 0 to 0.04). At the same time, the size of processed data is significantly reduced (i.e., the size of processed data decreases from 1725 to 182 in 2013) that would save much computational time and resource. Consequently, the AI-based approach for updating parameters in this paper is effective and practical for bridge deterioration model and gets rid of manual intervention.

4. Conclusions

Artificial intelligence is a computer science on the research and application of the law of the activities of human intelligence, and it has a broad application prospects in the practice of engineering. In bridge management, the information about the condition of bridge performance is increasing with time, so the parameter updating of bridge deterioration model is very critical for bridge management. To solve the problems of manual intervention and demanding for large computing resources of the conventional approach, an AI-based approach for updating parameters was presented. In this approach, the initial information is described by a prior distribution, and new information is viewed as a sample; then the posterior distribution is deduced, which can be used to update the deterministic model parameter. In addition, this approach is verified to be effective by practical data in a case study. The findings indicate that the new approach is a formal and mathematically consistent updating approach, which can be used to realize the parameter self-updating of bridge deterioration model without manual intervention and increase efficiency of updating parameters.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Ensemble of Chaotic and Naive Approaches for Performance Enhancement in Video Encryption

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Owing to the growth of high performance network technologies, multimedia applications over the Internet are increasing exponentially. Applications like video conferencing, video-on-demand, and pay-per-view depend upon encryption algorithms for providing confidentiality. Video communication is characterized by distinct features such as large volume, high redundancy between adjacent frames, video codec compliance, syntax compliance, and application specific requirements. Naive approaches for video encryption encrypt the entire video stream with conventional text based cryptographic algorithms. Although naive approaches are the most secure for video encryption, the computational cost associated with them is very high. This research work aims at enhancing the speed of naive approaches through chaos based S-box design. Chaotic equations are popularly known for randomness, extreme sensitivity to initial conditions, and ergodicity. The proposed methodology employs two-dimensional discrete Henon map for (i) generation of dynamic and key-dependent S-box that could be integrated with symmetric algorithms like Blowfish and Data Encryption Standard (DES) and (ii) generation of one-time keys for simple substitution ciphers. The proposed design is tested for randomness, nonlinearity, avalanche effect, bit independence criterion, and key sensitivity. Experimental results confirm that chaos based S-box design and key generation significantly reduce the computational cost of video encryption with no compromise in security.

1. Introduction

The advancements in networks and communication have promoted the usage of digital multimedia data in the field of education, commerce, defense, and entertainment. Usage of video applications such as video messaging, video conferencing, video surveillance, and Internet video sites such as YouTube is becoming increasingly popular and pervasive. Telemedicine is an application of clinical medicine and information technology where consultation, medical procedures, and examinations are performed remotely using interactive audiovisual media. These applications generate and transmit large amount of sensitive data in a resource constrained environment characterized by lower bandwidth, frequent packet drops, quality of service concerns, and limited computational resources of the communicating devices. The increasing use of video based applications demands not only secure algorithms for transmission and storage of videos but also efficient algorithms to reduce computational overhead.

Confidentiality for multimedia data is offered by means of encryption, in which the legitimate users can only gain access to data with the secret keys possessed by them. Video encryption algorithms are classified based on the way of encrypting data. Fully Layered Encryption (Naive Encryption) considers the whole content of video stream as a sequence of bits and encrypts with text based symmetric 3 algorithms such as Advanced Encryption Standard (AES), Blowfish, and Triple DES and so forth [1, 2]. As these algorithms have no strong evidences of cryptanalysis reports, they provide complete security to the whole multimedia stream. However, because of the complexity involved in key generation and encryption, delay increases and overload will be unacceptable for real time processing.

To increase the encryption efficiency, a large number of permutation and selective video encryption strategies are proposed in the literature. Permutation based video encryption algorithms scramble the bytes within every frame of a video stream. In Zig-Zag permutation [3], an individual 8×8 block is mapped onto 1×64 vector by using a random permutation list. Shi and Bhargava [4] proposed a methodology to save computational time by combining MPEG compression and data encryption at the same time. As MPEG compression rate depends upon Huffman codeword list, the same codeword list is used as a secret key for permutation. Permutation based algorithms are vulnerable to known plain text attack [5], because by comparing the ciphered frames with the original frames, the permutation list can be easily figured out.

Selective encryption algorithms encrypt only selective subset of bytes within video frames to reduce the volume of data to be encrypted and at the same time to preserve a sufficient level of security. Meyer and Gadegast [6] proposed a scheme in which RSA or DES was used to encrypt MPEG video stream at four levels of security: (i) encrypting all stream headers, (ii) encrypting all stream headers and all DC and lower AC coefficients of intracoded blocks, (iii) encrypting I-frames and all I-blocks in P and B frames, and (iv) encrypting all the bit streams. However, special encoder and decoder are required to read unencrypted stream. In Aegis scheme proposed by Spanos and Maples [7], the intraframes, video stream header, and the ISO 32-bit end code of the MPEG stream are encrypted using DES in Cipher Block Chaining (CBC) mode, while the P and B frames are left unencrypted. The limitation of this idea is that the stream headers are predictable and broken by plaintext-ciphertext pairs [8]. Socek et al. [9] proposed a video encryption algorithm that securely encrypts the video stream but also preserves data correlation in the video sequence. An improvised H.264/AVC comprehensive video encryption scheme is proposed by Wang et al. [10] in which the intraprediction mode, motion vector difference, and quantization coefficients are encrypted and the encryption keys are generated based on the cryptographic hash function.

From the literature, it can be inferred that there is no scheme that fits all applications. Permutation and selective encryption algorithms can reduce the computational overhead, but for complete and provable security of video in sensitive applications such as telemedicine, military, and business meetings, the entire video stream needs to be encrypted. Hence, development of video encryption algorithms encrypting the entire video stream at low computational cost is inevitable.

The proposed system encrypts the entire stream of video data but with a significant reduction in computational time through the application of Henon map. Henon map is employed in video encryption to address two levels of security: (i) ensemble of dynamic and key-dependent S-box with symmetric algorithms (Blowfish and DES) and (ii) generation of one-time keys for simple substitution ciphers.

2. Background

2.1. S-Box. In cryptography, an S-box is a basic component of symmetric key algorithms, which performs substitution. It is typically used to establish a nonlinear relationship between the key and the cipher text. An S-box should exhibit cryptographic properties such as bijection, strict avalanche, output bits independence, and equiprobable input/output XOR distribution. The input to an S-box could be an "n" bit word, but the output can be an "m" bit word, where "m" and "n" are not necessarily the same. An S-box can also be keyed or keyless and linear or nonlinear. S-boxes help the block ciphers to exhibit two important characteristics, namely, diffusion and confusion. The idea of diffusion is to hide the relationship between the plain text and the cipher text, which will frustrate the adversary who uses cipher text statistics to find the plain text. The idea of confusion is to hide the relationship between the cipher text and the key, which will frustrate the adversary who uses cipher text to find the key.

2.2. Analysis of S-Box Design in Symmetric Cryptosystems. Eight S-boxes are used in DES, in which each S-box is constructed as a table of four rows and sixteen columns [11]. The design of S-box in DES is not open, not key-dependent, and not dynamic, which could serve as a point of vulnerability. In Blowfish, four S-boxes are used each of which is constructed as a one-dimensional array of 256 elements [12]. Even though the S-box values are key-dependent, 521 Blowfish encryptions are required to generate all values thereby leading to a significant increase in computational time. The S-boxes of AES are prone to being attacked and hard to mask for its nonlinear characteristic. In addition, large amounts of circuit resources in chips and power consumption are involved in protecting S-boxes against power analysis [13]. Many researchers have proposed alternative design of S-boxes to address the above-mentioned limitations. The following four approaches are normally followed in S-box design [14].

(i) Random: pseudorandom numbers are used to generate the entries in the S-boxes.

(ii) Random with testing: the S-box entries are chosen randomly and tested against various criteria and the values that do not pass are not considered.

(iii) Human-made: the S-boxes of DES are designed in this mode, where the entries are filled manually. However, the approach is difficult to carry out for large S-boxes.

(iv) Math-made: S-boxes are generated by using mathematical principles, and hence they have proven security against linear and differential cryptanalysis. Use of chaotic equations is one such mathematical way of S-box design.

2.3. Related Works. Discretized chaotic maps are used for generating dynamic and cryptographically strong S-boxes by Tang and Liao [15]. The cryptographic properties such as bijection, nonlinearity, strict avalanche, output bits independence, and equiprobable input/output XOR distribution of these S-boxes were analyzed in detail. A method for designing S-box based on chaos and genetic algorithm is proposed by Wang et al. [16]. The problem of S-box generation is converted into a Travelling Salesman Problem (TSP). A stronger S-box is obtained because of the complete utilization of traits of chaotic map and evolution process. Attempts have also been made to design strong S-boxes based on chaotic Lorenz system [17] and Tangent delay for elliptic cavity chaotic sequence [18]. Lambić [19] has used an idea of ensemble of chaotic maps and composition method to generate random and bijective S-boxes. It is based on compositions of S-boxes from a fixed starting set. The sequence of the indices of starting S-boxes used is obtained by using chaotic maps. Chandrasekaran et al. [20] have proposed a method based on logistic map for S-box generation and reported the reduction in computational costs for text and image encryption on integration with Blowfish algorithm.

Henon map has been used for pseudorandom number generation [21] and for encryption of satellite imagery [22]. Most of the research articles have analyzed the effect of one-dimensional chaotic system for S-box generation. This research work employs two-dimensional discrete Henon map in construction of S-boxes and in generation of one-time keys for video encryption, as Henon map offers better pseudo randomness than logistic maps [23].

2.4. Henon Map. The random-like, unpredictable dynamics and simplicity in realization of chaotic systems make them suitable for cryptographic applications. The Henon map is a two-dimensional discrete dynamical system introduced by Michael Henon as a simplified model of Lorenz system [24]. Henon map takes a point (x_n, y_n) in the plane and maps it onto a new point (x_{n+1}, y_{n+1}) as defined by the equations

$$\begin{aligned} x_{n+1} &= y_{n+1} + 1 - \alpha x_n^2 \\ y_{n+1} &= \beta x_n. \end{aligned} \tag{1}$$

The desired statistical properties can be obtained from the generated values if the input values are as follows. "α" can be in the range of 1.16 to 1.41. "β" can be in the range of 0.2 to 0.3. "x_0" can be in the range of −1 to 1. "y_0" can be in the range of −0.35 to 0.35. Skip value can be in the range of 80 to 1000.

Henon map is found to exhibit good chaotic behavior for values $\alpha = 1.4$ and $\beta = 0.3$, as shown in Figure 1.

A minute variation in the initial parameters even in ten-millionth place value of the chaotic systems could yield widely divergent results. In any cryptographic application, the property of confusion aims to make the relationship between statistics of cipher and key as complex as possible to thwart attempts to discover the key. The property of diffusion aims to make the statistical relationship between the input and cipher as complex as possible. The extreme sensitiveness to initial conditions of the Henon map makes it suitable for cryptographic applications due to the enhanced confusion and diffusion properties.

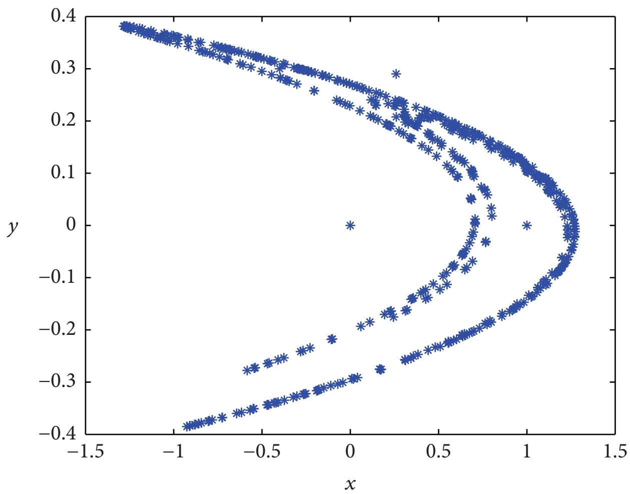


Figure 1: Chaotic behavior of Henon map.

3. Application of Henon Maps in Proposed S-Box Design

Certain applications such as business and military meetings require a very high level of security. Extreme level of security could be achieved only by naive approaches of video encryption but with high computational costs. In order to increase the encryption speed and to reduce the computational cost of symmetric algorithms, the proposed S-box design using Henon maps can be integrated into the chosen symmetric algorithms.

3.1. Implementation Procedure. The various steps involved in integration of the proposed S-box design with symmetric algorithms including Blowfish and DES are as follows.

Step 1 (exchange of secret parameters). For generation of S-boxes, the following parameters are to be exchanged using the public keys of the communicating entities or through a secret channel.

- P_1: The parameters of the Henon map α, β and seed values x_0, y_0.
- P_2: The number for decimal places of the mantissa that are to be supported by the calculating machine.
- P_3: The number of iterations after which the first value is to be picked for generating keys.
- P_4: The skip value to be maintained for picking successive values thereafter.

Step 2 (encoding of chaotic values into binary sequence). (1) Iterate the two-dimensional equations of the Henon map for a predefined number of times, which is specific to the crypto algorithm chosen for encryption. Process the result in two one-dimensional arrays $\mathbf{x}$ and $\mathbf{y}$ of length $d = wm/2$. The number of iterations (N_c) is given by

$$N_c = \frac{1}{2}(wmv), \tag{2}$$

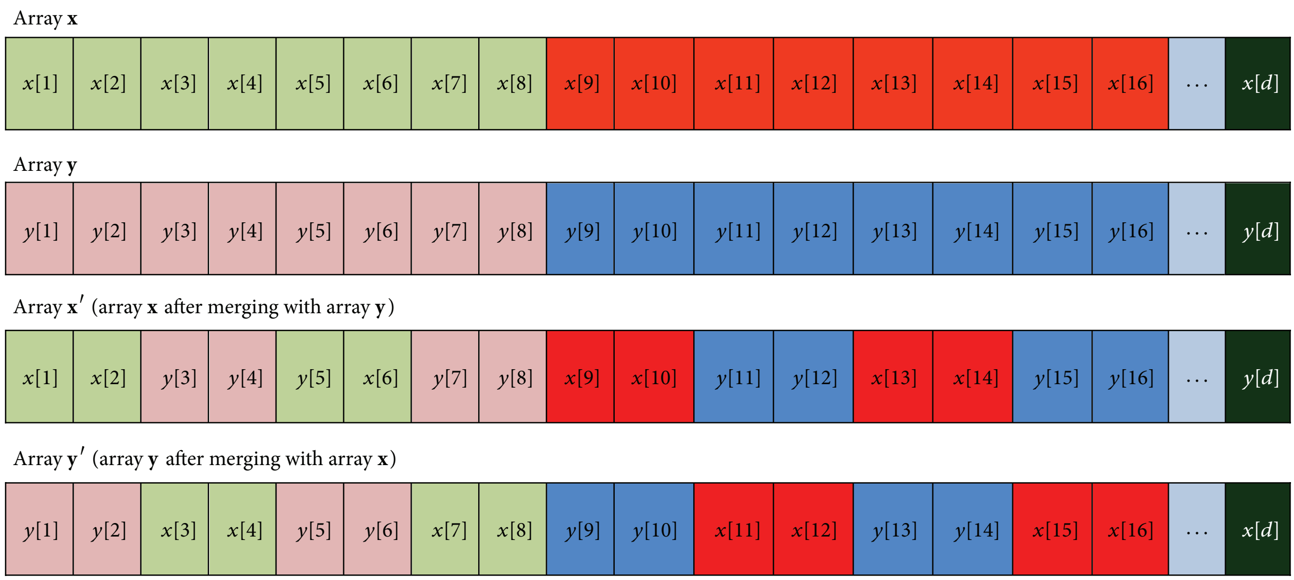


Figure 2: Encoding of chaotic values into binary sequence.

where "w" represents the word length of S-box elements. "m" represents the total number of S-box elements. "v" represents the skip value to be maintained for picking up successive values in iterations of Henon map equations.

(2) Split the arrays $\mathbf{x}$ and $\mathbf{y}$ into subarrays of length equal to the word length (w) of the S-box elements.

(3) Mix the individual subarrays with each other at predefined crossover points as illustrated in Figure 2.

(4) Calculate the medians (τ_x' and τ_y') of each individual array of $\mathbf{x}'$ and $\mathbf{y}'$.

(5) To generate a binary sequence, compare each element of x' and y' with its median, τ_x' and τ_y', respectively. If $x[i]$ is greater than τ_x', encode as "1"; else encode as "0." If $y[i]$ is greater than τ_y', encode as "1"; else encode as "0."

(6) Partition each binary sequence across the word length and use alternatively to generate the individual S-box elements.

A sample 8-bit S-box with eight rows and eight columns (64 elements) is illustrated in (3). It could be inferred that the S-box entries are almost random and nonlinear:

$$\begin{array}{|c|c|c|c|c|c|c|c|} 237 & 141 & 152 & 228 & 230 & 78 & 109 & 141 \\ \hline 134 & 87 & 101 & 59 & 184 & 57 & 134 & 86 \\ \hline 158 & 102 & 25 & 157 & 152 & 224 & 216 & 217 \\ \hline 99 & 129 & 182 & 99 & 101 & 25 & 100 & 102 \\ \hline 102 & 230 & 102 & 97 & 153 & 142 & 9 & 102 \\ \hline 155 & 102 & 81 & 182 & 57 & 134 & 101 & 100 \\ \hline 109 & 152 & 216 & 9 & 217 & 143 & 2 & 152 \\ \hline 36 & 54 & 83 & 118 & 101 & 57 & 99 & 108 \end{array}. \quad (3)$$

Step 3 (video encryption). Let V be the video to be encrypted consisting of frames $F_1, F_2, F_3, \ldots, F_z$. The S-boxes generated are integrated with the Feistel cipher structure of both Blowfish and DES to perform encryption. The entire video stream is treated as a sequence of bits and is completely encrypted with the corresponding crypto algorithm. A detailed description of Blowfish and DES can be found in [11] and [12], respectively.

3.2. Experimental Results and Discussion

3.2.1. Performance Enhancement. Integration of the proposed S-box design with DES aims to enhance security through dynamic and key-dependent S-boxes. Existing S-box design of DES is static and hence it is possible for an opponent to perform cryptanalysis by exploiting its weaknesses [25]. Cryptanalysis of DES mainly focuses on the construction of eight S-boxes. The present work increases the resistivity of DES against cryptanalysis. The significant advantage of key-dependent S-boxes is that it is computationally impossible to analyze the S-box values ahead of time to look for weaknesses.

Existing Blowfish algorithm requires 521 encryptions for generation of P-arrays and S-boxes. The proposed S-box design when integrated with Blowfish results in significant reduction of time by eliminating the 521 encryptions. Thus, the proposed S-box design makes Blowfish suitable for memory limited and low powered devices with no compromise in security.

3.2.2. Nonlinearity. Nonlinearity is the major requirement of any S-box design. The proposed design of S-boxes is tested for nonlinearity against different criteria [25] as given below. As a sample, the S-box generated for integration with DES is used as a test case and is shown in (4)

	00	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**
00	15	6	7	2	0	9	8	15	0	6	3	12	1	11	6	3
01	10	2	12	7	1	7	11	4	3	14	15	4	11	14	8	6
02	13	14	0	8	1	0	3	3	4	3	14	8	7	14	0	13
03	8	0	11	10	14	15	4	5	9	2	6	13	3	8	1	7

. (4)

The S-boxes thus generated are tested against various criteria specified for quality checks and the results are as follows.

Criterion 1 (no output bit of any S-box should be too close to a linear function of the input bits). The relation between the input and output bits is plotted in Figure 3 for different seed values. The graph depicts a highly nonlinear relationship between the input and output bits.

Criterion 2 (if two inputs to an S-box differ in exactly one bit, the outputs must differ in at least two bits). For the given inputs [110000, 110001] and [100000, 110000], which differ by one bit, the corresponding outputs are [0011, 1000] and [1101, 1000] which differ by at least two bits.

Criterion 3 (if two inputs to an S-box differ in the two middle bits exactly, the outputs must differ in at least two bits). For the given inputs [001100, 000000] and [110011, 111111], which differ by two middle bits exactly, the corresponding outputs are [1001, 1111] and [1001, 0111] which differ by at least two bits.

Criterion 4 (if two inputs to an S-box differ in their first two bits and are identical in their last two bits, the two outputs must not be the same). For the given inputs [110011, 000011] and [100000, 010000], which differ in two middle bits exactly, the corresponding outputs are [1001, 0010] and [1101, 1010] which differ by at least two bits.

The proposed S-box design has been tested for the above four criteria for 30 test cases drawn from 10 samples of S-boxes. About 99% of the test cases were found satisfactory with respect to all criteria.

3.2.3. Key Sensitivity Analysis. For a good cryptosystem, the output should vary significantly by a larger number of bits for minor changes in input. A sample of generated and encoded values in decimal format for minor changes in seed values of Henon map is shown in Table 1. It can be inferred that the generated S-box values for varying inputs that differ by a minor value result in significant changes in the output, thus making crypt analysis practically infeasible.

3.2.4. Avalanche Effect. A desirable property of any cryptographic algorithm is that the key space should be discretized in such a way that two ciphers encrypted by two slightly different keys $k_1, k_2 \in K$ should be completely different. The proposed methodology has been examined with Blowfish encryption for text inputs with a difference of 1 bit retaining all the other inputs to be similar. If a function is to satisfy the strict avalanche criterion, then each of its output bits should change with a probability of one half whenever a single input bit is complemented. The deviation has been analysed in each round of Blowfish encryption for the input parameters, Key = 0×78906543, $X_0 = 0.26$, $Y_0 = 0.29$, skip value = 100 and slightly differing plain text input 1 = $0 \times 1234876509874563$, and plain text input 2 = $0 \times 1234876509874562$. It can be observed from Table 2 that the output of each round significantly differs by large number of bits thereby exhibiting good avalanche effect.

4. Application of Henon Maps in Generation of Random Keys for Simple Substitution Cipher

Certain applications like pay TV require medium level of security but high speed for video encryption. To facilitate this, the chaotic values generated by the Henon map are encoded as one-time keys. As the encryption and decryption involve a simple and reversible XOR operation of keys with all the pixels of every frame, the time taken for encryption and decryption is significantly reduced.

4.1. Implementation Procedure. The steps involved in generation of random keys for simple substitution cipher operating in counter mode of operation are as follows.

Step 1 (exchange of secret parameters). In addition to the exchange of secret parameters (P_1, P_2, P_3, P_4) as mentioned in Section 3.1 (Step 1), another parameter for increment of seed value (P_5) is also exchanged. For random generation of keys, the seed values X_0 and Y_0 are incremented by the value of P_5 during encryption of every frame.

Step 2 (encoding of chaotic values into binary sequence). (1) Iterate the Henon map for a predefined number of times, which directly depends upon number of frames and count of pixels in each frame. The number of iterations (N_k) is given by

$$N_k = \frac{1}{2}(zlbv), \tag{5}$$

where "z" represents the number of frames in the video sequence. "l" represents the number of pixels in every frame. "b" represents the number of bits used for pixel representation. "v" represents the skip value to be maintained for picking up successive values in iterations of Henon map equations.

Table 1: Sample S-box values for various word lengths.

Word length = 8		Word length = 32	
($X_0 = 0.26, Y_0 = 0.29$)	($X_0 = 0.2600001, Y_0 = 0.2900001$)	($X_0 = 0.26, Y_0 = 0.29$)	($X_0 = 0.2600001, Y_0 = 0.2900001$)
187	24	3141672960	411361735
66	132	1089722552	1963237847
32	225	2974290515	3333557337
0	199	745678432	1933694433
64	117	1584790750	450043474
243	4	412521365	2414960418
216	161	1965090619	2698793360
184	215	80970080	25003267
177	198	881337089	1165496663
72	178	1622861053	1773666820

Table 2: Analysis of avalanche effect.

Rounds	Output in hexadecimal	
	Input = 0x1234876509874563	Input = 0x1234876509874562
1	27A03F47 A976A765	CD179EFA 243AA986
2	DFCA3C31 6753E7FF	F71F213D 6753E7FE
3	1A8D4140 6E822E62	7407EF0D 4657336E
4	EEE60256 36FF6720	9CEEFEB3 5875C96D
5	8748B200 B093FE88	6B655854 C29B026D
6	ECEAD64C 9FDE2195	2DCBAAAC 73F3CBC1
7	FE41A7F1 99CA3177	A706709E 58EB4D97
8	01A13BCD FA922691	50D35728 A3D5F1FE
9	ACEAD2AC E6F9BACC	702B5C9B B78BD629
10	BEC8D3A8 CC503651	997D1993 1091B866
11	DA02AA08 745FE49C	C7916952 53EA2EA7
12	D49EEFBF 8116B9CB	E5CB473C 9C857A91
13	6EC5BDAD 7832823A	B7E64AD6 49672AB9
14	5BC94D80 291906EA	A17A4A21 F03AF191
15	88E1BB56 F1BF0320	BB7180AF 0B0C0481
16	F15CDE0B5BEADA19	9E85D079 687AE1E0

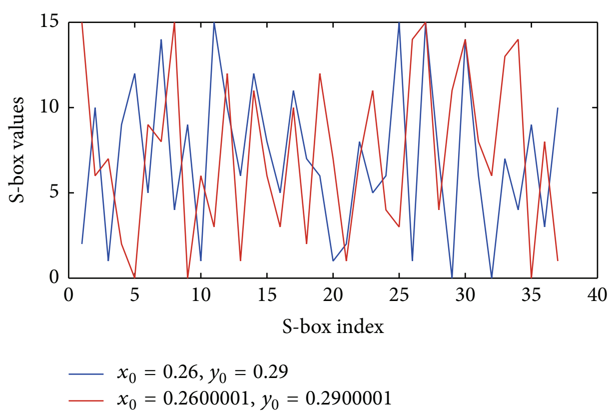


Figure 3: Nonlinear relations between input and output bits.

(2) Create a key table consisting of all possible 2^b keys, which is sequentially arranged and indexed.

(3) Encode the chaotic values generated to the indices of the key table using the same procedure as described in Section 3.1 (Step 2). Identify the key for encryption from the corresponding index of the key table.

Step 3 (video encryption). Let V be the video to be encrypted consisting of frames $F_1, F_2, F_3, \ldots, F_z$. The number of pixels in every frame is represented by "l" and "b" bits are used for every pixel representation.

(1) Perform XOR operation on every pixel ($R_1, R_2, \ldots, R_l$) of the frame (F_1) with the keys ($K_1, K_2, \ldots, K_l$) in keyset (S_1) to produce the ciphered frame (C_1) as illustrated in Figure 4.

(2) Update the seed (P_1) using the increment parameter (P_5) to generate new random keys for encryption of every frame, thereby making the crypto system as strong as one-time pads. To enhance the speed of encryption, the key generation can be done as a preprocessing step prior to encryption.

4.2. Experimental Results and Discussion. The key generation algorithm has been implemented in MATLAB in Microsoft

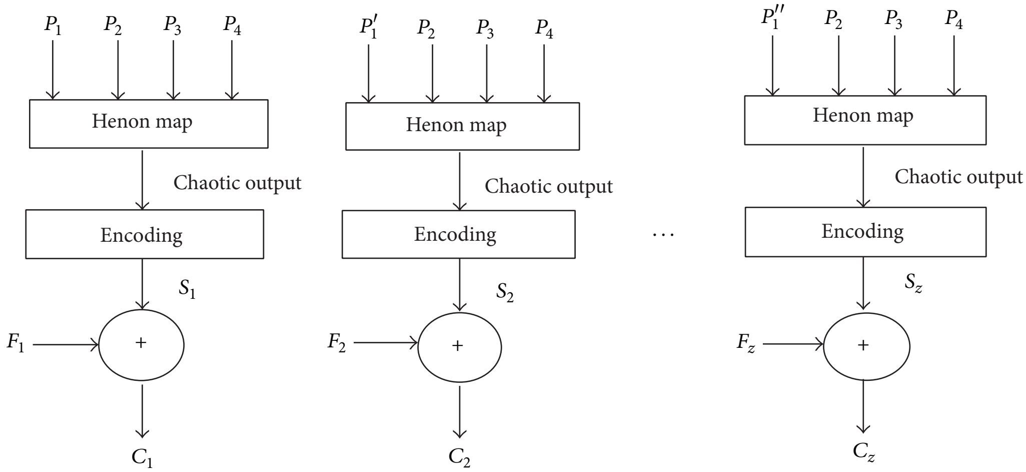
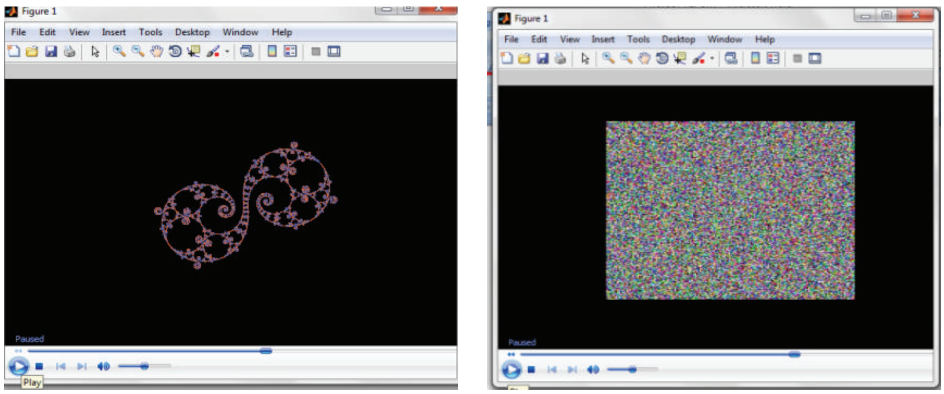


FIGURE 4: Miniature substitution cipher with counter mode of operation.



(a) Original video file

(b) Encrypted video file

FIGURE 5: Encryption of video file.

TABLE 3: Properties of "dfs.avi".

Attribute	Value
Number of frames	102
Height	240 pixels
Width	320 pixels
Frame rate	15 fps
Bits per pixel	24 bpp
Size of video	1.0839 MB
Video format	RGB24

Windows environment and is tested with various video formats. The strength of the proposed design and its suitability for video encryption have been tested for key space, key sensitivity, resistance against statistical attacks, randomness, and computational time. The experimental results are demonstrated for "dfs.avi" file and its properties are enlisted in Table 3.

The results of encrypting the video file and an individual frame are illustrated in Figures 5 and 6, respectively. It can be inferred that encryption with the proposed scheme provides complete visual degradation, thus providing no clue to deploy statistical and differential attacks.

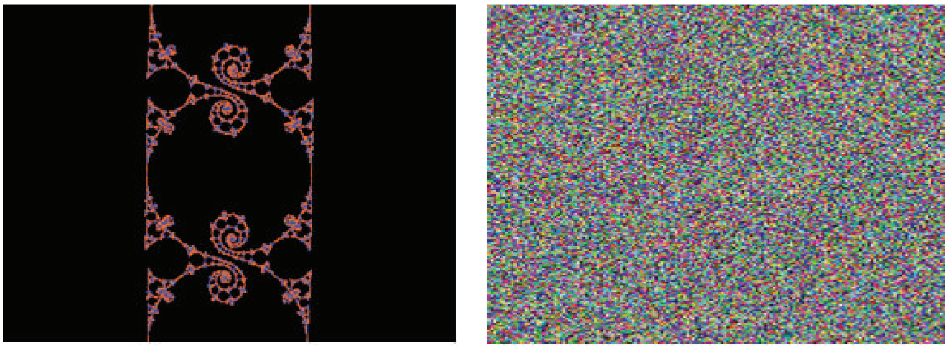
4.2.1. Key Space Analysis. Attempt to recover the original data by trying out all possible keys is called Brute force attack. The strength of any cryptographic algorithm depends on the size of its key space to make Brute force attack infeasible. The values of S-boxes depend on the initial seed and its related parameters associated with the chaotic equation. The initial seed "X_0" is in the range of −1 to 1 and "Y_0" is in the range of −0.35 to 0.35. The key space also depends upon the number of decimal places of the mantissa that are supported by the calculating machine which is approximately infinitely large, thus making Brute force attack computationally infeasible.

4.2.2. Resistance against Statistical Attacks

(A) Correlation Coefficient. A high level of correlation exists among pixels in adjacent frames of a video and in order to make a video encryption algorithm resistant towards crypt analysis, the correlation between the adjacent frames

Table 4: Correlation coefficient.

Frame number	Frame number	Correlation coefficient of red component		Correlation coefficient of green component		Correlation coefficient of blue component	
		Before encryption	After encryption	Before encryption	After encryption	Before encryption	After encryption
1	2	0	−0.0065	0	−0.0066	0	−0.0020
2	2	1	1	1	1	1	1
2	3	0.8089	−0.0074	0.7937	−0.0067	0.8211	0.0089
3	4	0.7958	0.00022	0.7744	0.0037	0.7946	0.0087
4	5	0.7799	0.0014	0.7631	0.0036	0.7728	0.00087



(a) Original video frame (b) Encrypted video frame

Figure 6: Encryption of a single frame of "dfs.avi" video.

of the ciphered video must be minimized. The correlation coefficient (ρ) is calculated by

$$\rho = \frac{\left(G\sum_{j=1}^{G} p_j q_j - \sum_{j=1}^{G} p_j \sum_{j=1}^{G} q_j\right)}{\sqrt{\left(G\sum p_j^2 - \left(\sum_{j=1}^{G} q_j\right)^2\right)\left(G\sum p_j^2 - \left(\sum_{j=1}^{G} q_j\right)^2\right)}}, \quad (6)$$

where p and q are the intensity values of two pixels in the same position of adjacent frames and G represents the total number of pixels in a frame. From Table 4 it is inferred that there exists negligible correlation between plain and ciphered images, thereby providing no clue for statistical crypt analysis.

(B) Histogram Analysis. Statistical attacks are made by exploiting the predictable relationships between the plain and cipher frame pairs. Significant changes in the histograms of original and cipher frames reveal the strength of the algorithm against statistical attacks. The histograms of red, green, and blue components of original and ciphered frames are illustrated in Figures 7, 8, and 9, respectively. Since the histograms of the ciphered frame are uniformly distributed and significantly different from the original frames, they do not provide any clue to deploy statistical attacks.

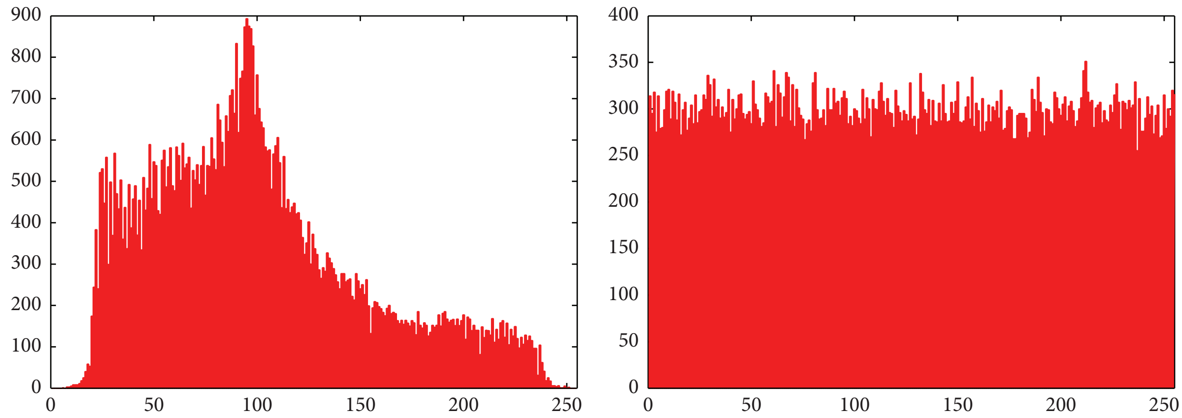
4.2.3. Randomness Test. The National Institute of Standards and Technology (NIST) has recommended certain set of statistical tests for detecting deviations of a binary sequence from randomness [26]. The randomness testing is required in many cryptographic, modelling, and simulation applications. Table 5 shows the results of the statistical test on the generated binary sequence. The sequence is said to exhibit random behaviour if the value obtained in each of the statistical tests is greater than or equal to 0.01. The result clearly shows that the values obtained for all the tests are greater than 0.01 and hence the proposed design has passed the randomness testing.

5. Overall Performance Analysis of Henon Maps in Video Encryption

The performance metrics for video encryption such as visual degradation, trade-off between encryption ratio and speed, compression friendliness, and format compliance are examined in both applications of Henon maps, namely, (i) integration of proposed S-box design with DES and Blowfishand (ii) generation of random keys for simple substitution cipher in counter mode of operation.

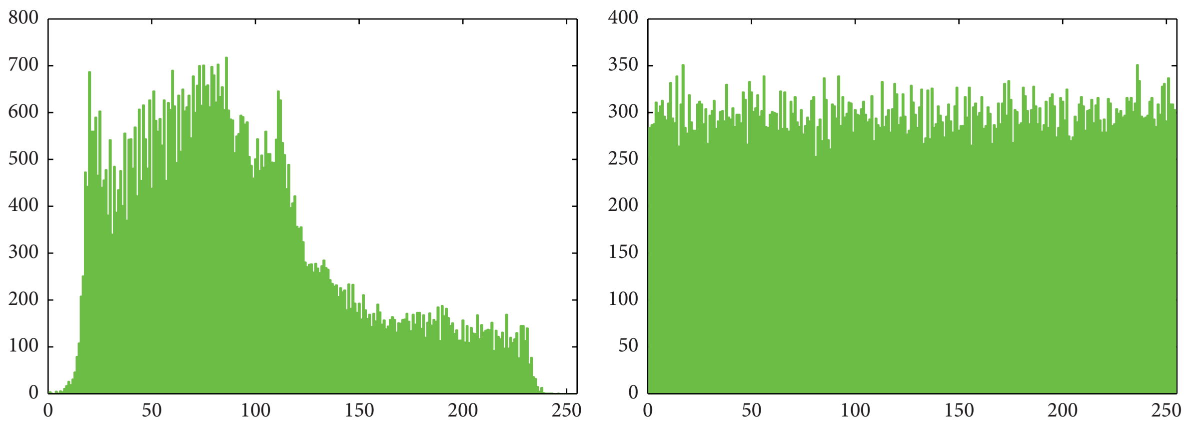
5.1. Visual Degradation. Visual degradation measures the perceptual distortion of the video data with respect to the plain video. It can be inferred from Figures 5 and 6 that the proposed methodology on integration with symmetric algorithms offers high visual degradation and hence can be used for encrypting sensitive data. As a miniature substitution cipher, the algorithm provides high degradation at a less computational time.

5.2. Encryption Ratio versus Speed. Encryption ratio measures the ratio between the size of the encrypted part and the



(a) Original frame (b) Ciphered frame

Figure 7: Histograms of red component.



(a) Original frame (b) Ciphered frame

Figure 8: Histograms of green component.

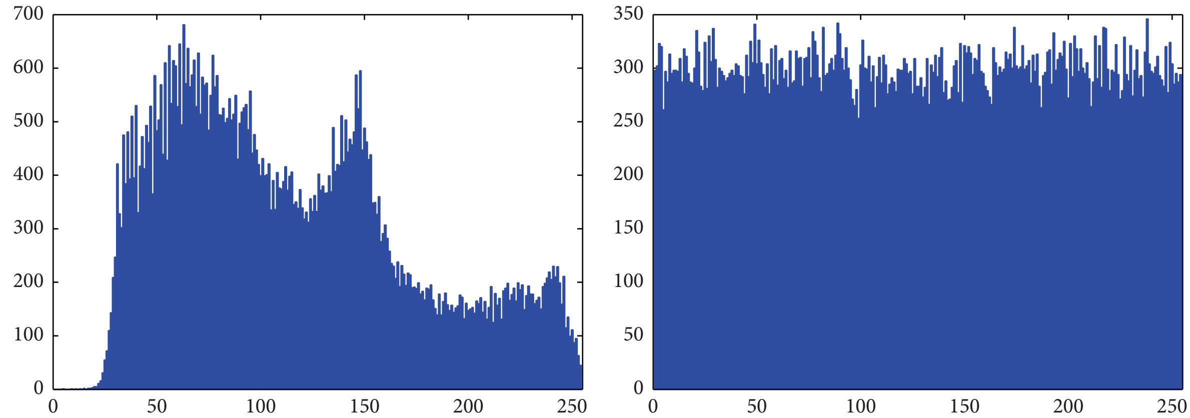
whole data size. In order to increase the speed of the encryption algorithm, encryption ratio has to be minimized. A balance between security and speed is achieved by completely encrypting the entire data and at the same time increasing the speed of encryption through modified design of S-boxes. The proposed design significantly reduces the time taken for encryption/decryption by eliminating the 521 iterations of Blowfish making it suitable for real time processing. In application of the proposed design for generation of random key, the encryption is carried out in counter mode which involves parallel processing of multiple frames for significant reduction in encryption/decryption time. Since every frame is operated independently of the other frame, propagation of bit errors in transmission is completely eliminated and hence the quality of decrypted video is ensured.

5.3. Compression Friendliness. The proposed video encryption algorithm is compression friendly as it has no impact on the efficiency of data compression. Also the size of the data is not increased with reference to the original size of the file.

5.4. Format Compliance. The syntax of the encrypted video stream of the proposed video encryption algorithm is also compliant with the standardized syntax of the compressed video stream. The encryption does not disturb the standardized syntax structure of the video stream such as the frame header, slice header, and the block header.

6. Conclusion and Future Work

This research work deploys the concept of Henon map to create dynamic S-boxes for symmetric key cryptosystems and for generation of random keys for simple substitution ciphers. The randomness, sensitivity to initial conditions, and ergodicity make Henon map suitable for S-box generation and one-time pads. The ease of encoding and transformation technique makes the system suitable for memory limited and low powered devices. The proposed methodology attains a high level of security at a less computational time. Experimental results prove the robustness of the algorithm against statistical attacks, key sensitivity tests, and randomness test and in performance enhancement. Future work may be attempted at deriving mathematical proofs for nonlinearity. The proposed video encryption algorithm may be extended and tested for mobile and cloud environments.



(a) Original frame

(b) Ciphered frame

Figure 9: Histograms of blue component.

Table 5: Randomness testing.

NIST statistical tests	Results
Frequency (Monobit) test	0.8597
Runs test	0.7234
Discrete Fourier transform	0.1048
Block frequency	0.8233
Longest runs test	0.0103
Cusum test	0.6547
Serial test	0.7770
Matrix rank test	0.5339
Overlapping template test	0.9060
Linear complexity test	0.9428
Nonoverlapping template test	0.6608
Random excursions variant test	0.6681
Random excursions test	0.6920

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

A Push on Job Anxiety for Employees on Managing Recent Difficult to Understand Computing Equipment in the Modern Issues in Indian Banking Quarter

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Stress management can be defined as intervention planned to decrease the force of stressors in the administrative center. These can have a human being focus, aimed at raising an individual's ability to cope with stressors and the implementation of the CRM is essential to establish a better performance of the banking sector. Since managing stress and customer relationship management are becoming crucial in the field of management the work has forecasted them in a wide range of dimensions. This paper organizes few preliminary concepts of stress and critically analyzes the CRM strategy implemented by banking sector. Hence the employees of the Banking Industry have been asked to give their opinion about the CRM strategy adopted by banks. In order to provide the background of the employees, the profile of the employees has been discussed initially. The profile of the employees along with their opinion on the CRM practices adopted at Banking Industries has been discussed. In our work progresses we have been taken of two main parameters for consideration and it detriment in which area stress are mainly responds, and also the paper envelopes certain valuable stress management tactics and techniques that are particularly compassionate for people who have been working in the banking sector. Also an attempt to diagnose the impact of underside stress of day to day life in mounting a bigger level stress upon the employees has been made. Further development has been made with a detailed parametric analysis of employee stress conducted with the wide range of key parameters and several rounds of experiments have been conducted with techniques as Kolmogorov-Smirnov test, Garrett ranking, and ANOVA; the work ensures to pave way for an accurate measure in customer handling. The questionnaire is planned to be distributed to 175 employees in the Madurai district banks.

1. Introduction

The implementation of the CRM is essential to establish a better performance of the Banking Industry and to avoid stress of employees. The present study critically analyzes the CRM strategy implemented by Banking Industry and find out the stress level of employees. Hence the employees of the Banking Industry have been asked to give their opinion about the CRM strategy adopted by banks. In order to provide the background of the employees, the profile of the employees has been discussed initially. In this research article, the profile of the employees and their opinion on the CRM practices adopted at Banking Industry has been discussed. The paper deals with the systematic presentation of analyzed data followed by the interpretation of data. Statistical analysis of data enables researchers to organize, evaluate, interpret, summarize, and communicate numeric information. Descriptive statistics is used to describe data and inferential statistics to draw inferences about a population based on collected sample data.

Banking sector not only has been playing a leading role within the financial system in India but also has a significant socioeconomic function, making intruding into the interiors of the economy and is being considered as one of the fast developing areas in the Indian financial sector too.

Customer service is an integral part of Banking Industry but also while handling the number of customers the stress level will automatically increase. It is the duty of research to do in-depth study to identify the key success factors in Banking Industry, in terms of stress level of the employees so as to survive in intense competition and increase the market share.

CRM is a customer focused business strategy that aims to increase customer satisfaction and customer loyalty by offering a more responsive and customized service to each customer. CRM is about managing customers for better understanding and to serve them. Keeping the importance of CRM and its service excellence in view, this study is an attempt to analyze management of the customer relationship in banking sector particularly, Banking Industry of India (banks) in Madurai district of Tamil Nadu.

2. Objective Is to Analyze Influence of the CRM Factor

(i) To examine the relationship between employee's job stress and their involvement in organizational works which in turns in CRM.

(ii) To examine and understand how the employees know about CRM strategy in bank.

(iii) To analyze the most important category of customers approaching the employees.

(iv) To analyze the satisfaction level of the customer services provided by Banking Industry and find out the occupational status of the employees.

(v) To find out and analyze the opinion about the CRM system in an integral part of the work in banks.

(vi) To analyze and find out stress level while solving the problem of the account. holders and clearing the doubts of the account holders regarding loan details and other operations.

3. Need for the Present Study

Banking sector in India is presently witnessing a phenomenal growth. We presently have over 27 public sector nationalized banks, 31 private banks and 38 foreign banks. All these banks cater to over 114014 ATMs across the country. But the average population per bank branch (APBB) as on March, 31, 2013, is only 12,100. This means that minimum numbers of banks are catering to a huge volume of people and the growing economy puts the stress right on the shoulders of the bank employees which makes the current study an inevitable one. Although several researches have been made in this area, this work tries to bring in a multidimensional study on the stress in the banking setup.

4. Literature Review

Workplace stress places significant psychological, physiological, and financial costs on both the individual employee and his or her organization. Workplace stress has been associated with the etiology of physical disorders such as heart disease, hypoadrenia, immunosuppressant, and chronic pain. In addition, the psychological impact of workplace stress includes depression, persistent anxiety, pessimism, and resentment. The impact of these symptoms on organizations is significant as these symptoms lead to hostility in the workplace, low morale, interpersonal conflict, increased benefit expenses, decreased productivity, and increased absenteeism (Colligan and Higgins [1]).

Job stress can arise from different environment of work like organizational or situational stress; it is from the characteristics of the workers themselves, that is, dispositional stress Riggio et al. [2]. Stress is a natural lesson in the life and every employee, even executives and managers, should be affected by this issue. According to survey about 100 million workdays are being affected due to stress problem among employees and nearly 50%–75% due to disease cause stress Bashir and Ramay [3].

Absence and loss of employment are major causes of job stress in the organization. The ratio increases day after day because of organisation environment. They were the main hurdles of achieving goals and performance [4].

Employers need to be aware of how the population (organization) is changing with respect to age. For example, the new trends in the banking industry show an inclination towards more hiring of young and fresh business graduates. So, in near future, in most jobs, even top-level executives would be young people. This also poses another issue that young individuals are more aggressive and sensitive so they are more likely to fall prey to job stress, Du et al., [5].

Ho et al. [6] investigate the relationship between compensation benefit of employees on the basis of performance. Compensation relates to performance of employee in the organization and accordingly shows high performance as well as low performance of the employee.

Income has a major impact on the living standard of an individual. In reality, if it is said that it is the decider of the life-style of any individual, it would not be wrong. Income has also relationship with family life cycle which actually moulds the spending pattern of a family. Different researches have shown that the person with high income is having a different style of spending than low income groups' persons. If a person has a family to support and the number of households is large, then his only criteria of selection of a job would be the money which he would receive. So, any such individual who is being paid less while his expenditure is more would eventually experience job stress, Kanagaretnam et al. [7].

Adding to the pressures that workers face are new bosses, computer surveillance, fewer health, and retirement benefits, and the feeling they have to work longer and harder just to maintain their current economic status. Workers at every level are experiencing increased tension and uncertainty. They are undergoing Job Stress to be precise. This study examines the relationship between Job Stress and Employee Retention and consequences of high stress on Indian Industries.

Shah et al. [8] culture create society and exchange views. It changes from generation to generation. Human nature changes fill the individual gap.culture changes individual behavior also. The symbols may be intangible (attitudes, beliefs, values, and language) or tangible (tools, housing, products, and works of art). Cultures do change over time. Every organization has its own distinct culture. If an employee fails to comply with the organizational norms and culture, he would be proving himself to be odd against all so he would be more prone to have stress at his workplace.

Bano and Kumar Jha [9] analyzed the impact of organizational stress among the public and private sector employees and found that both of them face reasonable levels of stress in work environment. There is no significant difference in terms of total stress levels and work experience but educational qualifications contribute certain differences. In the study by Vishal et al. [10], employees of both public sector and private sector banks face the same level of stress. Among the various stressors in the public sector banks, lack of efficient manpower and performance pressure play major roles. The other contributing factors include family demands and unexpected contingencies followed by job rigidity. The employees of the private banks also face the same stressors along with certain new aspects like adaptability to change and performance pressure which also have some effect on stress.

Joshi and Goyal [11] studied the exposure of stress during the mergers of Bank of Rajasthan with the ICICI Bank. Due to this kind of mergers, both banks create a positive effect on their market base and ensure that the customers of the bank are satisfied. During the merger, the employees of the Bank of Rajasthan were totally against the merger process. Their research found that after the completion of merger the employees satisfaction levels were very low and the stress was very high. They discussed the cultural fit and the human resource policy framework during the merger and felt that if mergers and acquisitions were not managed properly the stress at workplace will increase rapidly. According to a recent study conducted by Dr. Samartha et al. [12], the entry of private and multinational banks, the public sector banks were forced to introduce new concepts and revise their existing setup and product line-ups. This forced the employees of the public sector banks to work beyond their office hours. Hence, the stress levels are at par with the private bank employees.

Upon analyzing the employee turnover in banking sector, Shukla and Dr. Sinha [13] found that the important factors for employee turnover are effective job satisfaction and conducive work environment. The significance level for both these variables are very high and they imply that, irrespective of better salary compensation, the employees have a huge desire to push themselves into new avenues so as to seek a better work environment and job satisfaction. They suggested that if the career-oriented employees were given more freedom and opportunity in the work environment they may not switch companies in a short time. Callous management attitude and excessive workload will stress the career oriented employees and push them to seek better alternatives. Shahid et al. [14] discussed the six components of job stress: lack of administrative support, excessive work demand, problematic customer relations, coworker's relationship, family and work life balance, and riskiness of job. They studied the relationship between stress and performance. The results depicted that stress naturally affects employee performance.

Job stress leading to a counterproductive work behavior has been discussed by Aftab and Javeed [15]. Various factors like poor communication skills, forcing the employees to work beyond their capacity, an unfair performance evaluation system, inappropriate salaries, and working conditions have been analysed. Their findings have proved that job stress leads to counterproductive work behavior thereby affecting the work environment. Sharma et al. [16] discovered that the commercial banks are required to wake up to the fact that stress has multifaceted relationship with performance-related benefits. Performance benefits can lower the perception of underutilization at workplace. On the other hand, it may increase the workload of employees. Nevertheless, an organization aims at reducing the role stress plays at workplace. It involves an uphill task in optimizing utilization of the capabilities of the workforce and at the same time not increasing the workload of employees beyond a functional level.

Shah and Hasnu [17] identified the key factors that have effect on employees' job performance. Job instability is one of the reasons for job stress among employees. This in turn affects the job performance. This study is conducted to understand the causal relationship between job instability and job performance. It aims to identify the key moderators of job performance in the banking sector of Pakistan. Six hypotheses are tested using AMOS 17.00 by applying the technique of structural equation modeling. The findings revealed that all the hypotheses are accepted with significant level. It is proven that there exists a negative relationship between job performance and job stress as well as job instability. This would mean that increase in job instability and job stress would decrease job performance. Job involvement has shown a significant and positive impact on job performance. The direct and indirect relationship showed that all the three variables are the mediators of job performance. Removing job instability and job stress is impossible but organizations can make efforts to reduce them to the minimum level.

Abdullah et al. [18] found that the employees who are extroverts, that is, the people who are more talkative and social, outperform the introverts, that is, who are confined to their own self. Similarly, the employees who were cooperative with their coworkers and superiors perform better than the noncooperative ones. Their study has suggested that proper personality analysis has to be performed before recruiting banking professionals. Adjei and Kwasi Amofa [19] assessed the job related stress at the Barclays Bank and found out that the majority of the employees felt huge stress at work. Their results showed that the long working hours contributed to the stress. Various stress relaxation techniques were suggested to overcome the negative aspects of stress.

5. Tool of Data Collection and Research Question

Statistical Package for Social Sciences version 20.0 (SPSS) was used in the analysis and interpretation of data. Two public sector banks and two private sector banks were considered for the purpose of this research. A well-structured questionnaire containing 39 questions leading to 131 variables was used to collect data. The questionnaire was distributed to the banking employees directly and testing was survey primarily

Table 1: Know about CRM strategy of banking sector.

Sl. number	Rank Scale how do they know about CRM strategy	1 75	2 60	3 50	4 40	5 25	Total 110	Total Score	Average	Rank
1	Through training									
	f	32	44	13	9	12	110	6350	57.73	II
	fx	2400	2640	650	360	300				
2	Through journals and magazines									
	f	5	13	56	32	4	110	5335	48.5	III
	fx	375	780	2800	1280	100				
3	Orientation given by officials									
	f	53	15	4	30	8	110	6475	58.86	I
	fx	3975	900	200	1200	200				
4	Through colleagues									
	f	8	29	14	36	23	110	5055	45.95	IV
	fx	600	1740	700	1440	575				
5	Personal experience									
	f	12	9	23	3	63	110	4285	38.95	V
	fx	900	540	1150	120	1575				
	Total	110	110	110	110	110				

Source: computed.

conducted from 131 numbers of respondents. The particular information was composed of the banking employees at all three levels in banking sector. Interviews were conducted with the employees for assembly of the various sequences on their observation about their bank (association) and the troubles which they face both directly and indirectly while completing every day jobs. The respondents were interviewed on the issues touching the stress levels of the workers, bang of relations pressures on their employment, expectations from their responsibility, up to what level they are happy, and likely suggestions for overcoming the adversities of stress by evaluating the individual initiatives and managerial initiatives.

6. Analysis of Data

The data will be analyzed to determine any differences between the stress levels of employees and their impact on reducing stress. So the researcher attempts to analyze the demographic profiles such as gender, age, sex, marital status, qualification, family size, occupational status, monthly income, association with Banking Industry, number of new account openings, and sectioning of loans are taken for the mode of the selected customers. For the purpose of analysis, 110 employees were taken into consideration.

7. Findings and Discussions

(i) This paper also includes an analysis of data collected by representing it in tabular form along with interpretations.

(ii) The information collected was analysed for arriving at proper conclusion on the topic.

Table 2: Category of customers approaching.

Sl. number	Category	Number of employees	Percentage to total
1	Farmers	19	17.27
2	Businessmen	35	31.82
3	Professionals	40	36.36
4	Govt. employees	1	0.91
5	Private employees	15	13.64
	Total	110	100.00

Source: primary data.

In order to understand how the employees know about CRM strategy of bank employees Garrett ranking technique was employed and the results are given in Table 1.

7.1. Garrett Ranking Technique. Table 1 shows details about how the employees came to know about CRM strategy of Banking Industry in Madurai district. It is inferred that orientation given by officials ranked first, which represents a mean score of 58.86, through training ranked second, which represents a mean score of 57.73, through journals and magazines ranked third, which represent a mean score of 48.5, through colleagues ranked fourth, which represents a mean score of 45.95, and personal experience ranked fifth which represents a mean score of 38.95.

The most important category of customers approaching the employees includes farmers, businessmen, professionals, government employees, and private employees. The distribution of employees on the basis of category of customers approaching them is given in Table 2.

Table 3: At which stage the customers are approaching.

Sl. number	Particulars	Number of employees	Percentage to total
1	At the time of opening new account and long term deposit	37	33.64
2	At the time of new account and long term deposit	2	1.82
3	At the time of closing the deposit and settlement	7	6.36
4	At the time of closing the deposit in middle	1	0.91
5	At the time of getting loan	30	27.27
6	At the time of transfer of money in account	2	1.82
7	At the time of loan repayment	31	28.18
	Total	110	100.00

Source: primary data.

Table 4: Satisfaction with customer services provided by Banking Industry.

Sl. number	Particulars	Number of employees	Percentage to total
1	Yes	84	76.36
2	No	26	23.64
	Total	110	100.00

Source: primary data.

The analysis infers that the most important category of customers approaching the employees is professionals and businessmen which constitute 36.36 per cent and 31.82 per cent of the total, respectively.

The most important stages at which the customers are approaching the employees are classified to at the time of opening account and making deposit. The distribution of employees on the basis of the stages at which the customers are approaching is given in Table 3.

It is revealed from Table 3 that the most important stage at which the customers are approaching the employees is at the time of opening new account and long term deposit is 33.64 per cent, at the time of loan repayment 28.18 per cent, and at the time of getting loan 27.27 per cent to the total, respectively.

The satisfaction with the customer services provided by the Banking Industry may also determine the perception level of employees towards CRM in banking sector. The distribution of employees on the basis of satisfaction with the customer services provided by banking is given in Table 4.

Table 4 shows that 76.36 per cent of the employees are satisfied with the customer service provided by the banks while the remaining 23.64 per cent of the employees are not at all satisfied with the service provided by the Banking Industry.

The most important reasons how the employees are satisfied with the services provided by banks are classified into quick response, innovative service delivery, building relationship, good rapport, and financial security. The distribution of employees on the basis of how they are satisfied with the services provided by banks using Garret ranking technique is given in Table 5.

On the basis of the ranks assigned by the employees the impacting variables are analyzed through Garrett ranking techniques. It is evident from Table 5 that the employees have been much satisfied through customer service provided by banks in respect of the variables, quick response (61.61) mean scores followed by building relationship (61.38), innovative service delivery (47.20), good rapport (41.74), and financial security (38.07) in the order of priority. Hence it can be concluded that as bank is quick in responding to all its queries the employees are much satisfied with the service offered by Banking Industry.

The distribution of employees on the basis of meeting attended by them is given in Table 6.

It is inferred from Table 6 that, out of the total employees, 83.64 per cent said that they had attended the meeting conducted by banks, while the remaining 16.36 per cent said that they had not attended the meeting.

Ho: there is no significant difference among the age of the employees with regard to the opinion of CRM strategy. To test the above hypothesis one-way analysis of the variance is used (see Table 7).

Table 7 depicts that there is a significant difference among age with regard to the opinion of CRM strategy and hence null hypothesis (Ho) is rejected. Hence it is concluded that CRM strategy in Banking Industry has significant difference among age.

Ho: there is no significant difference among the occupational status of the employees and the opinion of CRM strategy in Banking Industry. To test the above hypothesis one-way analysis of the variance is used (see Table 8).

Table 8 shows that there is a significant difference among the occupational status of the employees with regard to the opinion of Banking Industry strategy and hence null hypothesis (Ho) is rejected. Hence it is concluded that CRM strategy in banks has significant difference among occupational status.

Ho: there is no significant difference among the category of customers of the employees about the opinion of CRM

Table 5: How you are satisfied with the services provided by banks.

Sl. number	Rank / Scale / satisfaction with customer services provided by LIC	1	2	3	4	5	Total	Total Score	Average	Rank
	Scale	75	60	50	40	25	110			
1	Quick response									
	f	41	45	5	16	2	109	6715	61.61	I
	fx	3075	2700	250	640	50				
2	Innovative service delivery									
	f	3	3	68	31	4	109	5145	47.20	III
	fx	225	180	3400	1240	100				
3	Building relationship									
	f	60	14	1	30	4	109	6690	61.38	II
	fx	4500	840	50	1200	100				
4	Good rapport									
	f	3	25	14	30	37	109	4550	41.74	IV
	fx	225	1500	700	1200	925				
5	Financial security									
	f	2	22	21	2	62	110	4150	38.07	V
	fx	150	1320	1050	80	1550				
	Total	110	110	110	110	110				

Source: computed.
Note. x: scale value; f: number of employees; fx: score.

Table 6: Attended the meeting of banks.

Sl. number	Particulars	Number of employees	Percentage to total
1	Yes	92	83.64
2	No	18	16.36
	Total	110	100.00

Source: primary data.

Table 7: ANOVA among age of the employees about the opinion of CRM strategy in Banking Industry in Madurai District.

Age group	Sum of squares	d.f.	Mean square	F	Statistical inference
Between group	1.325	4	0.331	3.432	0.011 $p < 0.05$ Significant
Within group	10.138	105	0.097		
Total	11.464	109			

Source: computed data.

Table 8: ANOVA among occupational status of employees about the opinion of CRM strategy in Banking Industry in Madurai District.

Age group	Sum of squares	d.f.	Mean square	F	Statistical inference
Between group	6.275	4	1.569	2.548	0.044 $p < 0.05$ Significant
Within group	64.643	105	0.616		
Total	70.918	109			

Source: computed data.

Table 9: ANOVA among the categories of customers approaching employees about the opinion of CRM strategy in Banking Industry in Madurai District.

Age group	Sum of squares	d.f.	Mean square	F	Statistical inference
Between group	4.462	4	1.116	1.763	0.142 $p > 0.05$ Not significant
Within group	66.456	105	0.633		
Total	70.918	109			

Source: computed data.

Table 10: Solve the problem of the account holders.

Sl. number	Particulars	Number of employees	Percentage to total
1	Yes	110	100.00
2	No	—	—
	Total	110	100.00

Source: primary data.

strategy in Banking Industry. To test the above hypothesis one-way analysis of the variance is used (see Table 9).

It is inferred from Table 9 that there is no significant difference among the category of customers approaching the employees with regard to the opinion of CRM strategy and hence null hypothesis (Ho) is accepted. Hence it is concluded that CRM strategy in banks does not have significant difference among category of customers.

The distribution of employees with regard to solving the problem of the account holders is given in Table 10.

Table 10 clearly shows that out of the total employees all of them said that they would solve the problem of the account holders.

7.2. How They Solve the Problem of the Account Holders. The most important ways by which the problem of the account holders is solved by the employees are classified into clearing the doubts of the account details, giving advice at the time of facing the problems, verifying all loan documents, providing moral support at all levels, and settling the grievance as quickly as possible. The distribution of employees on the basis of how they solve the problems of the account holders using KS Test is listed in Tables 11, 12, and 13.

7.2.1. KS Test. For the purpose of analysing whether there is any difference in the importance of ratings given by the employees on various statements, the hypotheses have been formulated. The hypothesis has been tested by the researcher with the help of Kolmogorov-Smirnov test (here known as KS Test).

Formula $D = O - E$

D refers to calculated value;

O refers to cumulative observed proportion;

E refers to cumulative expected proportion.

7.2.2. Testing of Hypotheses. To assess the employees opinion regarding solving the problem of account holder in banks five statements, namely, clearing the doubts of the loan details, giving advice at the time of facing the problems, verifying all loan documents, providing moral support at all levels to them, and settling the grievances of the account holders as quickly as possible have been used and hypotheses are framed and tested by applying KS Test.

Cumulative observed proportion is calculated on the basis of observed frequency, that is, observed number. The total number of employees is 110. About 110 employees have given their opinion for gradation “Strongly Agree.” In the case of first statement the observed properties are calculated by dividing 60 of total employees. The resultant value (0.60) helps us to grade the observed properties. For all gradations, the same method of calculation is followed. On the basis of observed proportion, cumulative observed proportion is calculated.

Cumulative expected proportion is calculated on the basis of expected proportion. Since there are five gradations, each gradation (i.e., 0.20) is assigned as expected proportion. On the basis of expected proportion, the cumulative expected proportion is calculated.

For each gradation, the difference between cumulative observed proportion and cumulative expected proportion is calculated. The largest difference will be taken as calculated value. The calculated value is compared with the table value (Tables 11, 12, and 13).

If the calculated value is greater than the table value, the null hypothesis is rejected. On the other hand if the calculated value is less than the table value, the null hypothesis is accepted.

Result

Calculated value: (largest difference) = 0.60.

The table value at 95 per cent confidence level = $1.36/\sqrt{110} = 0.13$.

As the calculated value (0.60) is greater than the table value (0.13), the null hypothesis is rejected. Hence, there is difference in the importance of ratings given by the employees in clearing the doubts of the account and loan details in banks in Madurai district.

Result

Calculated value: (largest difference) = 0.40.

The table value at 95 per cent confidence level = $1.36/\sqrt{110} = 0.13$.

As the calculated value (0.40) is greater than the table value (0.13), the null hypothesis is rejected. Hence, there is

Table 11: Clearing the doubts of the account and loan details, KS Test.

Sl. number	Opinion	Observed number	Observed proportion	Cumulative observed proportion	Expected proportion	Cumulative expected proportion	$D = O - E$
1	Strongly agree	45	0.41	0.41	0.20	0.20	0.21
2	Agree	65	0.59	1.00	0.20	0.40	0.60
3	No opinion	0	0.00	1.00	0.20	0.60	0.40
4	Disagree	0	0.00	1.00	0.20	0.80	0.20
5	Strongly disagree	0	0.00	1.00	0.20	1.00	0.00

Table 12: Giving advice at the time of facing the problems, KS Test.

Sl. number	Opinion	Observed number	Observed proportion	Cumulative observed proportion	Expected proportion	Cumulative expected proportion	$D = O - E$
1	Strongly agree	1	0.01	0.01	0.20	0.20	−0.19
2	Agree	66	0.60	0.61	0.20	0.40	0.21
3	No opinion	43	0.39	1.00	0.20	0.60	0.40
4	Disagree	0	0.00	1.00	0.20	0.80	0.20
5	Strongly disagree	0	0.00	1.00	0.20	1.00	0.00

Source: computed data.

difference in the importance of ratings given by the employees in giving advice at the time of facing the problems in banks at Madurai district.

The employees are asked to give their opinion at five-point scale ranging from “Strongly Agree” to “Strongly Disagree” for the following statements and the mean, standard deviation and coefficient of variation is given in Table 13.

7.3. Opinion about CRM System Is an Integral Part of the Work in Banks. “It is fully accepted that the CRM system is an integral part of work in bank”. The researcher has identified nine statements to study the opinion about the CRM systems as an integral of part of work in bank.

7.3.1. Coefficient of Variations. The opinion of the employees about the CRM system as an integral part of the work in banks has been analysed through mean value ($\overline{X}$), standard deviation (σ), and coefficient of variation. Table 13 shows the details.

Table 13 explicates that “CRM helps to build customer loyalty” has got 4.97 as mean value, 0.16 as standard deviation, and 3.22 as coefficient of variation, “CRM enhances customer loyalty” has got 4.74 as mean value, 0.50 as standard deviation, and 10.55 as coefficient of variation, “CRM can attract new customers” has got 4.77 as mean value, 0.46 as standard deviation, and 9.64, “CRM Boost Customer’s Confidence” and “CRM Benefits industry performance and productivity” have got 4.02 as mean values, 0.13 as standard deviation, and 3.23 as coefficient of variations followed by “CRM objective is to frame customer database,” “CRM is undertaken by employee to approach customers,” Existence of CRM practices throughout all the level, and so on. Hence it is concluded that the opinion of the employees regarding the CRM System is an integral part of their work in banks.

8. Summary of Findings and Recommendations

This study provides an in-depth appraisal of stress existing in the banks positioned in the Madurai district of Tamil Nadu, India. The results of a range of tests have proven that pressure is invariably in audience everywhere in the bank organization. Bank staff are subjected to mounting levels of stress. The work situation staggers under the influence of stress and thereby is principal to a fruitless environment. In addition, interpersonal work connection is also under fire as the test outcome shows a decline in assistant support in the banks. Irrespective of the type, that is, management owned public sector banks or private banks, employees working under both sectors face extensive stress. It has also been found that the work experience and marital status have a collision on stress in workplace. Entertainingly, though the marital status adds its own weight on strain, the size of family does not have any endproduct on stress. The ever-escalating menace of traffic congestion in today’s roads contributes to the stress in the work environment. The tests have proved that the distance from home to headquarters played a momentous role in inducing stress. The coworker and controller support were poor in the bank under cram. The results revealed that the human resources face considerable heaviness because of the way out support from their colleagues.

The art of coping with the stress using various strategies is the need of the day. It should be unwritten that the failure to protect the human being assets will lead to a calculated

Table 13: Opinion about the CRM system in an integral part of the work in banks.

Sl. number	Opinion of employees	$\overline{X}$	σ	C.V
1	CRM enhances customers loyalty	4.74	0.50	10.55
2	Existence of CRM practices throughout all the levels	3.44	0.52	15.12
3	CRM is undertaken by employee to approach customers	3.80	0.40	10.53
4	CRM objective is to increase better relationship among the account holders	3.85	0.45	11.69
5	CRM objective is to frame customer database	2.87	0.53	18.47
6	CRM can attract new customers	4.77	0.46	9.64
7	CRM helps to build customer loyalty	4.97	0.16	3.22
8	CRM boosts customer's confidence	4.02	0.13	3.23
9	CRM benefits industry performance and productivity	4.02	0.13	3.23

Source: computed data.

decay of a working culture. Banks should habitually organize destressing encampment to help the employees relieve their stress. The human resources have to be educated about the stress and its pessimistic impact on the family and work atmosphere. Stress buster techniques have to be educated to the employees. The secretarial setup has to be effectively redesigned so as to remove more work with little endeavor. The role of every employee should be defined clearly, so that role conflicts are null and void. Every major bank with more than 50 human resources shall have a separate space allotted for meditation room and a minipower fitness center. The people shall be encouraged to formulate use of these services and the banks can also think about introducing incentives to those people who use them commonly. Frequent get-together should be planned to bridge the gap between the supervisors and employees. This creates stronger bonds among coworkers.

9. Conclusion

Stress has practically invaded our life in the contemporary 21st century. We can never envisage a superlative world that does not have the part of strain in its day to day life. The bank exchange is the very hard and boring process; when compared to other areas it gives more stress than any other present surroundings. The character of employee obligation forms the vertebral column of any commerce and is inescapably responsible for administration of unbeaten business. So, the issue of job nervous tension has to be addressed with due concern and consideration. It has to be determined to improve the efficiency at workplace. In the present study we have addressed only a few demographic variables with the mention of the stress and analyze the various impact of coworker support and superintendent support to the employees. More delving into this subject can be taken up in the future so as to improve the capacity of the psychotherapy.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Priority Based Congestion Control Dynamic Clustering Protocol in Mobile Wireless Sensor Networks

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Wireless sensor network is widely used to monitor natural phenomena because natural disaster has globally increased which causes significant loss of life, economic setback, and social development. Saving energy in a wireless sensor network (WSN) is a critical factor to be considered. The sensor nodes are deployed to sense, compute, and communicate alerts in a WSN which are used to prevent natural hazards. Generally communication consumes more energy than sensing and computing; hence cluster based protocol is preferred. Even with clustering, multiclass traffic creates congested hotspots in the cluster, thereby causing packet loss and delay. In order to conserve energy and to avoid congestion during multiclass traffic a novel Priority Based Congestion Control Dynamic Clustering (PCCDC) protocol is developed. PCCDC is designed with mobile nodes which are organized dynamically into clusters to provide complete coverage and connectivity. PCCDC computes congestion at intra- and intercluster level using linear and binary feedback method. Each mobile node within the cluster has an appropriate queue model for scheduling prioritized packet during congestion without drop or delay. Simulation results have proven that packet drop, control overhead, and end-to-end delay are much lower in PCCDC which in turn significantly increases packet delivery ratio, network lifetime, and residual energy when compared with PASCC protocol.

1. Introduction

The high-tech advancement of microelectromechanical systems (MEMS) technology, processor designing, and wireless communication technology has made wireless sensor network (WSN) possible. It comprises tiny sensor nodes that are scattered in a physical space, organized into a cooperative network, and able to interact with their environment by sensing and monitoring physical and environmental parameters. WSNs are used in a wide range of applications from the civil sector to military [1–5]. The proposed protocol could widely be used in detecting natural disasters such as floods that occur in river originating from ice caped mountains and thus preventing life loss. Sensor nodes use wireless communication to collaborate to fulfill their tasks like reporting event to a centralized location called a base station (BS) for further processing to get valuable and needful information. The BS acts as a gateway between sensor node and end user and allows a user to productively sense and monitor from a distance.

The sensor nodes have to meet the requirements that come from the specific application such that they might have to be small, cheap, and energy efficient, they have to be equipped with the right sensors to compute and communicate the event to the base station. There are many technical difficulties which need to be overcome before WSN can be practically used. Thus network architecture needs to be modified to meet the specific needs of sensor nodes. Sensor nodes have the ability to withstand harsh environmental conditions and also due to their small size, the nodes are very constrained in all the resources. They have limited battery power, processing speed, storage capacity, and bandwidth. Because of the small battery size, the lifetime of a node is dependent on its capacity to conserve power. Depending upon the application, nodes may operate batteries for days, months, or even a year. Hence, to extend the lifetime of the sensor nodes, battery power needs to be effectively utilized. In WSNs, most of the energy consumed is during communication rather than by computation. Thus, energy efficient routing protocols need to be developed in order to effectively and uniformly utilize the energy among the sensor nodes.

The best routing protocol to suit for energy constrained network is cluster based routing protocols. These protocols organize the nodes into clusters. The number of clusters depends upon the application. There should be optimum number of clusters. Each cluster has one designated node called cluster head (CH) which is responsible for collecting data from its cluster members (CM) and transmits it to the BS. When compared to the conventional routing protocol, cluster based protocols reduce energy dissipation by eight times.

According to the nodes behaviour, WSNs can be classified as static or mobile. When compared with mobile nodes static nodes have several drawbacks [6, 7]. It is difficult to provide guaranteed optimal coverage using static nodes. Static failure node always hinders the communication in the network, which in turn affects connectivity and network quality. As the nodes move around the network, the number of packets to be routed to the BS varies drastically. This may cause congestion in the network, which results in packet loss. Time sensitive applications need data to be routed immediately without delay; otherwise the data will become useless. Network congestion can be avoided either by increasing link capacity or by controlling data rates [8–11].

To address these issues, in this paper, we proposed a novel Priority Based Congestion Control Dynamic Clustering Protocol (PCCDC) in WSNs. It is designed with the following objectives:

(i) To provide complete coverage and connectivity, mobile nodes are introduced and they are organized into clusters dynamically to minimize energy consumption.

(ii) To reduce packet drop and to provide a high packet delivery ratio (PDR), congestion is computed at intra- and intercluster level using linear and binary feedback methods, respectively.

(iii) An appropriate queue model is designed in each node to avoid prioritized packet drop or delay during congestion.

This paper is organized as follows. Section 2 discusses the related work. In Section 3, we describe the detailed framework of the proposed PCCDC protocol. Simulation results are discussed in Section 4, and Section 5 concludes the paper along with the future scope.

2. Related Works

In this section, we provide a brief overview of the various research efforts carried out to control congestion in WSN. Several works related to congestion only dealt with flat topology [12–17] but cluster based congestion control protocols can solve many constraints in WSN.

Congestion control for multiclass Traffic (COMUT) [18] is a scalable and distributed cluster based mechanism for supporting multiple classes of traffic in WSN. In COMUT nodes are organized into clusters, with each cluster having the ability to monitor congestion within it. Based on the congestion estimate, the nodes in the clusters then adjust the sending rate to mitigate congestion. To do this, sentinel roles are assigned to sensor nodes to proactively monitor the network and collect statistics to infer the collective level of congestion. Regulation of sensor rates and coordination between cluster nodes is achieved by exchanging only small amounts of control packets between the sentinel sensors along flow paths. It also has the capability to operate successfully over multiple underlying routing infrastructures and fading channel conditions.

Congestion avoidance altering routing (CAAR) protocol [19] is a cluster based congestion avoidance protocol. It is introduced to reduce routing instability and to conserve energy in a resource constrained sensor network. It utilizes local data preservation strategies during congestion. Then it reallocates the traffic by altering route after detection of congestion which improves data transmission reliability. This altering routing protocol also provides load balancing in the network which in turn enhances life cycle of the clusters.

Rapid Congestion Control Algorithm (RCCA) [20] uses cluster topology for controlling congestion in WSN. It discusses the target application like earthquake and forest fire monitoring where transmitting emergency packets to the base station as soon as possible is much more important than conserving energy of the sensor node. Srinivasan and Murugappan [21] proposed a transport protocol for congestion avoidance in WSN based on cluster topology. The number of sensor nodes in each cluster depends on desired accuracy. The nodes are arranged in a tree topology in such a way that a node which is CH in one cluster can be CM in another cluster and sink can always be a root node. To avoid congestion for both continuous and event based sensor network, it uses hop-by-hop congestion control scheme to transmit data to the corresponding parent nodes until they reach the sink.

Energy efficient congestion control protocol [22] adjusts the data transport rate to minimize energy consumption. Congestion control is done using the sum of the node weights. Each node adds its weight with the received weight downstream and passes it to upstream. The source obtains sum of all weight information and uses it for adjusting the rate. Clustering algorithm to partition sensor nodes is done based on the sending rate and similarity of data obtained. After cluster formation nodes within the cluster communicate with its Cluster Head alternatively on a schedule to save energy.

Priority based application specific congestion control clustering protocol (PASCC) [23] integrates the mobility and heterogeneity of the nodes. PASCC detects congestion in WSN based on the type and priority of the captured data. CHs prioritize packets based on the distance; the farther nodes get priority over those of nearby nodes. It also makes sure the extra resources consumed by farther nodes are utilized effectively. During congestion, prioritized packets are routed to BS due to their timeliness requirements and nonprioritized packets are dropped. PASCCC achieves better performance in terms of the network lifetime, energy consumption, data transmission, and other QoS metrics.

3. The PCCDC Protocol

In this section, we discuss the detailed framework of our proposed PCCDC protocol for WSNs. PCCDC is a protocol that considers mobile nodes with homogeneous nature which are organized dynamically into clusters. It is capable of detecting and alleviating congestion at intra- and intercluster level using linear and binary feedback, respectively. It also uses an appropriate queue model in each node to avoid prioritized packet drop or delay during congestion. The assumptions made for the protocol design are presented below.

(i) Nodes are deployed randomly in the sensor field with a same set of energy level.

(ii) Nodes are allowed to move around the sensing field at different speed to provide necessary coverage and connectivity.

(iii) Each cluster should have only one CH. Therefore the number of CHs always determines the number of clusters.

(iv) CMs are capable of adjusting their transmission power in order to reach their respective CH during a specific round.

(v) BS is always situated outside the sensing field which is mobile in nature and has the highest energy when compared with all the other nodes in the WSN.

3.1. Framework of PCCDC. Static WSN provides partial coverage of the sensing field. To provide complete coverage, the proposed PCCDC protocol uses mobile nodes which move around the sensing field to observe specific event that satisfies certain prespecified conditions. PCCDC is an application specific protocol which considers two application parameters, flooding (overflow of water) and temperature, which results in a multiclass traffic. Flooding is considered to happen when the temperature rises above the threshold value constantly in ice capped mountains. Since flooding occurs instantaneously, its traffic should be reported immediately to the base station. The packets in this case should be with less delay. This is called real-time packets. The real-time packets require preferential service when compared to the other. On the other hand sensing temperature and reporting to the base station happen periodically and are referred to as non-real-time traffic. In case of real-time traffic occurrence, traffic flows intersect with one another and region around the intersection creates a congestion hotspot [24]. This type of congestion is called forwarded congestion. It is difficult to identify the intersection points in forwarded congestion due to network dynamics. Dynamic clusters can handle forwarded congestion where the designated CH collects the traffic flow from its cluster members and aggregates and then communicates it to the BS. Appropriate queue models in each node provide a reliable delivery for real-time traffic when compared with non-real-time traffic.

3.2. PCCDC Mechanism. In this subsection, highlights of PCCDC protocol are given in consensus with congestion detection and control. It also provides an application overview, clustering methodology, queuing model, and energy consumption model.

3.2.1. PCCDC: An Application Specific Protocol. PCCDC is designed to support and sense two different application parameters. Each node is equipped with two types of sensors, one to monitor flooding and the other to sense temperature. The following are the assumptions made:

(i) The node senses temperature and transmits them continuously to their respective CH and then to BS.

(ii) The nodes start sensing flood only when the temperature reaches the threshold value; till then the flooding sensor remains idle.

Temperature packets have a low priority and result in a packet drop and some delay. On the other hand flood has high priority and should be reported without any delay and packet drop. When the sensed temperature s_T is less than the temperature threshold T_t value the nodes only sense temperature and update the CH. We set the value of T_t to 10°C. T_t is the minimum temperature required for flooding sensors to operate. When the sensed temperature s_T goes above the temperature threshold T_t, then flooding sensor is turned on and allowed to capture flooding packets.

PCCDC is suitable for monitoring ice capped mountains with higher altitude. The ice melts when the temperature rises and water formed causes flooding in the rivers which originates from them.

3.2.2. PCCDC: Clustering Operation. PCCDC is a dynamic cluster based protocol, which is iterative and provides different sets of clusters in each round. Every node maintains an update table. The update table holds information related to congestion of the neighboring nodes within the cluster. Each node computes its own weight and floods it to the neighbors which in turn update their update table. The fields in the update table are as follows:

⟨*node id, current queue length, residual energy, congestion level*⟩

where *node id* is the address of the neighbor, *current queue length* is the instantaneous queue length of the node and incremented or decremented by 1 whenever a packet is getting enqueued or dequeued, respectively, *residual energy* is the remaining energy of the node, and *congestion level* is found by comparing *current queue length* and *residual energy* against status table as discussed in Section 3.2.3.

PCCDC calculates the weight of node i which is given in the (1) and (2). Consider the following:

$$W_i = \alpha * \Delta_i + \beta * E_{Ri} + \gamma * Q_{Li}, \qquad (1)$$

where, α, β, and γ are nonnegative weight coefficients. It is equal to 0.33. Consider the following:

$$\Delta_i = \left| d_i - N \right|, \qquad (2)$$

where d_i is the degree of the node i by counting its neighbors, N is the maximum size of a cluster in terms of number of nodes, Δ_i is the degree difference for the node i, E_{Ri} is the residual energy for the node i, and Q_{Li} is the current queue length of the node i.

The nodes which have more weight in a particular region will act as a CH node for the current round. Each cluster is governed by a CH, which is responsible for gathering data produced by its CMs and detect congestion.

After CHs election, each CH broadcasts an advertisement packet to the neighbor nodes. The CHs contend for the medium using a CSMA (Carrier Sense Multiple Access) protocol with no further provision against the hidden-terminal problem. The non-CH nodes pick the advertisement packet with the strongest RSS in order to join themselves to a specific CH [18] using CSMA protocol. After a neighboring node decides to join to a specific CH, it unicasts a join-request message, which contains its identity and the identity of the specific CH. After cluster formation, it is the responsibility of a CH to allocate TDMA time slots to its members and broadcasts this in the broadcast schedule. This allows nodes to wake up only during TDMA time slot and gets an opportunity for transmitting data. Here TDMA based MAC (Medium Access Control) protocol is integrated with a simple routing protocol.

During data transmission phase, the sensed data from each CM can be forwarded to its CH node in the allocated TDMA slot. The numbers of slots assigned to CM are based on the current queue length and residual energy of the node at a particular time. Each CM can be assigned more than one slot in the current round. The communication between CH and its CMs is called intracluster communication. Then CH aggregates all the data packets transmitted by CMs to eliminate redundant packets. This reduces the number of packets forwarded to the BS, which in turn reduces energy dissipation and enhances the network lifetime. The communication between the CHs and the BS is called as intercluster communication.

The clustering period is defined as the start of the setup phase to the completion of the data transmission phase. Data aggregation is an energy efficient technique where packets from different neighbor are merged into a single packet, since it requires limited computational power and memory when compared with conventional transmission. Data aggregation gives exact information about the sensor field to the BS from where the end user can collect data. For every n packets received by CH during intraclustering, it only forwards m packets to the BS during interclustering, where m is much smaller than n. The m packets received in BS got a high degree of accuracy when compared with n packets. To balance the energy consumption over multiple nodes, the cluster head role is rotated periodically. The decision to become cluster head depends on the current buffer queue length and the residual energy at the node in PCCDC. When the node carries more space in its queue against the specified queue threshold and has more residual energy this node becomes CH for the particular round. It ensures that nodes consume energy more uniformly and try to avoid the black hole problem which increases the network lifetime.

3.2.3. PCCDC: Congestion Detection and Control. Mobile nodes in PCCDC protocol introduce unbalanced clusters. Hence the number of nodes in each cluster varies considerably. The clusters which carries more nodes are called over crowed clusters; the level of congestion in these clusters is high. During a multiclass traffic, congested cluster can delay or drop packets randomly which makes the network useless.

In PCCDC congestion is computed in two levels, intracluster level and intercluster level. In intracluster level, hop-by-hop congestion detection and control with linear feedback is used. When a CM "x" wanted to forward packets to CH through intermediate CM "y," then the node CM "x" would get the current queue length Q_L and the residual energy E_R of the node y in its update table. It is compared with the status table as shown in Table 1. The status value is derived using the current queue length Q_L and residual energy E_R. Based on the status value node x would transmit packet to node y; otherwise node x would find another neighbor to CH or selectively drop packets. This is called linear feedback [25] where nodes proactively monitor neighbor nodes queue length and residual energy which is piggybacked in the data packet header. In order to reduce the control overhead involved in transmitting packets, binary feedback was not considered at the intracluster level. Queue in each node is bound with two threshold values lower queue threshold Q_{TL} and upper queue threshold Q_{TH} which are used to find the level of congestion.

In intercluster level, end-to-end congestion detection and control with binary feedback is used. The CH sends all the aggregated data to BS through multihop communication which may contain congested CH. In PCCDC protocol, when a CH "x" wants to communicate with BS through intermediate CH "y," the node checks the current queue length and residual energy of CH "y" in its routing table. If the node y's current queue length was within the specified threshold with optimal residual energy, then node x would transmit the packet to node y. Otherwise node x adds a congestion bit in the control packet and then finds another route to CH or selectively drops the packets. This is called binary feedback [20]. When a network consistently drops packet, congestion become apparent. Packet drops are mainly due to queue overflow. Since the queue size is substantially limited it is difficult to control the queue overflow in sensor network. Congestion is mostly associated with the queuing model of each node.

3.2.4. PCCDC: Residual Energy Computation. The energy needed for routing packets depends on the residual energy at the link and at the node. It is the sum of energy at link and reciprocal energy available at the node [26]. This reciprocal function always assigns higher values to nodes having low residual energy. Consider as in Figure 1 that CM "x" wants to forward a packet to CH through an intermediate CM "y" or CM "z." The node computes the residual energy between CM "x" and CM "y" and between CM "x" and CM "z" and then the node decides the best next hop neighbor to reach CH. Assume that the energy level at the link between CM "x" and CM "y" and between CM "x" and CM "z" is the same

Table 1: Status table.

Status	Description
0	$Q_L < Q_{TL}$ with high E_R ready to forward
1	$Q_L < Q_{TL}$ with medium E_R ready to forward
2	$Q_L < Q_{TL}$ with low E_R forward packets based on priority
3	$Q_L > Q_{TL}$ && $Q_L < Q_{TH}$ with high E_R forward packets based on priority
4	$Q_L > Q_{TL}$ && $Q_L < Q_{TH}$ with medium E_R forward packets based on priority
5	$Q_L > Q_{TL}$ && $Q_L < Q_{TH}$ with low E_R forward packets based on priority
6	$Q_L > Q_{TH}$ with high E_R drop packets
7	$Q_L > Q_{TH}$ with medium E_R drop packets
8	$Q_L > Q_{TH}$ with low E_R drop packets

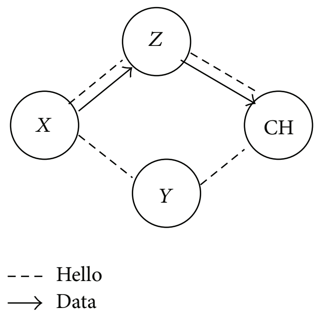

Figure 1: Residual energy computation.

which is equal to 2. But residual energy at CM "y" is 1 and at CM "z" is 2. Therefore energy required between CM "x" and CM "y" is $2 + 1/1 = 3$ and between CM "x" and CM "z" is $2 + 1/2 = 2.5$. It is concluded that the nodes which have low residual energy are assigned with higher value and vice versa. Here, CM "x" decides to forward the packets to CH through the neighbor node CM "z" based on its residual energy during intraclustering. Similarly, CH node also calculates the residual energy of its neighboring CH to reach the BS with lesser residual energy during interclustering.

3.2.5. PCCDC: Queue Model and Its Operation. The queue model in each sensor node plays a prominent role in the quick delivery of packets. Each sensor node has a queue to hold packets to be transmitted. Queue overflow occurs when a node receives packets with a higher data rate than it can transmit. To overcome this situation, a congestion control algorithm (Algorithm 1) can either reduce the data rate or selectively drop the packets which have lesser importance or reroute the packets through alternate path, which improves the throughput at the BS.

Figures 2 and 3 show a queue model introduced for sensor nodes in PCCDC. Each queue is bounded by two thresholds called lower threshold Q_{TL} and upper threshold Q_{TH}. This facilitates the queue in three different states such as accept state, filter state, and reject state. When the queue size is less than Q_{TL} the queue is in accept state, where all the

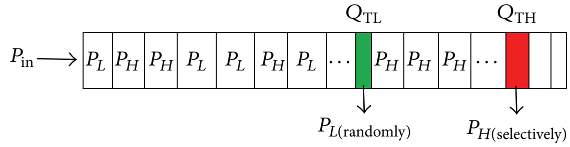

Figure 2: Queuing model of a CM sensor node.

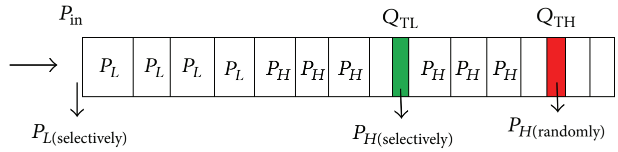

Figure 3: Queuing model of a CH sensor node.

packets are queued. This is a congestion free state, where the queue is scheduled using a FCFS algorithm. Congestion level can be measured through an exponentially weighted moving average of the instantaneous queue length. If it exceeds lower threshold Q_{TL} then the behaviour of the queue changes suddenly. It wou ld selectively enqueue packets based on priority. This is the filter state which indicates congestion is going to happen in the network. Afterwards, the average queue length is updated whenever a packet is inserted into the queue. This facilitates maximizing the number of priority packets getting enqueued during congestion. During this state the queue is scheduled using a priority algorithm. However, if the queue size exceeds Q_{TH}, then the node is said to be congested. Under this condition all packets are rejected until the current queue length Q_L is less than Q_{TH}. This state is called reject state.

As a result of these packet drops, source nodes and forwarding nodes waste and exhaust their battery power and finally create a routing hole. This can reduce network lifetime and overall network connectivity. Node senses events and assigns them priorities based on the packet type not on the locations of the nodes because event occurrences are not restricted to a specific location. Priority assignment can be done by reserving one bit in each packet header.

Since PCCDC is designed with homogeneous nodes, the queue models in both CM and CH are the same but have different queuing operations. If the CM's current queue length is within the lower threshold Q_{TL} then all the packets are queued in FCFS. Once it exceeds lower queue threshold Q_{TL}, then enqueue packets will contain priority bit set. In PCCDC, priority bit is set for all the real-time packets and a very low percentage of non-real-time packets. This avoids starvation problem for non-real-time packets.

High priority could be assigned to packets based on distance and sense value. In each cluster, CM far away from CH consumes more energy than nearby CM and also will expire earlier. Therefore, distance and sense value play an important role while assigning priority to packets. In WSNs, the nodes which are far away from CH could have meaningful data rather than the ones close to CH. Selective dropping or selective queuing is based on the packets proximity. The average queue length is updated after Q_{TL}. This facilitates

(a) Algorithm for queue model in CM
Input: P_{in} - incoming packet
Output: queue in which packet to be stored
Variables:
    Q_{TL}-Lower queue threshold
    Q_{TH} - Upper queue threshold
    Q_L- Current queue length
For each CM node
    For every packet to queue in
    Check the current queue length Q_L aginst Q_{TL} and Q_{TH}
        If ($Q_L < Q_{TL}$)
            Queue in both P_L and P_H, Queue act as FCFS
        Else if ($Q_L > Q_{TL}$) && ($Q_L < Q_{TH}$)
            Queue in P_H and drop P_L randomly
        Else
            Drop both P_L and P_H
        Endif
(b) Algorithm for queue model in CH
For each CH node
    Check the current queue length Q_L aginst Q_{TL} and Q_{TH}
        If ($Q_L < Q_{TL}$)
            Queue in P_L at tail selectively,
            Queue in P_H at the head
            Queue act as priority queue
        Else if ($Q_L > Q_{TL}$) && ($Q_L < Q_{TH}$)
            Queue in P_H selectively and drop P_L randomly
        Else
            Drop both P_L and P_H
Endif End

Algorithm 1: Algorithm for processing packets in CM and CH node.

maximizing the number of high priority packets getting enqueued during congestion. During this state the queue is scheduled using a priority algorithm. The scheduler first schedules high priority packets P_H followed by P_L low priority packets. However, if the queue size exceeds Q_{TH}, then the node is said to be congested. Under this condition all packets are rejected until the current queue length Q_L is less than Q_{TH}.

If the current queue length of CH is within lower queue threshold Q_{TL} low priority packets P_L are queued in at the tail and high priority packets P_H in the head. Queue acts as a priority queue right from the beginning. When the CH's current queue length exceeds lower queue threshold Q_{TL} all the low priority packets P_L are dropped randomly based on distance and sense value. But if it exceeds Q_{TH} then all the packets are rejected and the control signal is sent to its parent node to reduce its sending rate. The efficiency of the PCCDC system decreases the packet drop for high priority packets P_H to a large extent.

4. Performance Evaluation

Network simulator version-2 (NS2) [27] is used to simulate the proposed PCCDC protocol. NS2 is a network simulator that is widely used in wireless environments. The simulation parameters used are summarized in Table 2. The topology used in our simulation is a random topology with random mobility model where nodes are placed at a random position within the simulation area.

4.1. Performance Metrics. The performance of PCCDC protocol is evaluated using the following metrics:

(i) *Packet drop*: it is the average number of packets dropped in the sensor network due to congestion.

(ii) *Packet Delivery Ratio (PDR)*: it is the percentage of the total packets received successfully by the BS divided by the total packets produced by the sources.

(iii) *Control overhead*: it is the ratio of total number of control packets used in the network to the total number of data packets received.

(iv) *End-to-end delay*: it is the average time difference between the packets sent by the source node to the packet received by the base station.

(v) *Network lifetime*: it is the time taken for the energy of the first sensor node to fall from 0.5 J to zero. It is expressed in seconds.

(vi) *Residual energy*: it is the average energy consumed by sensor node during each round throughout the network.

Table 2: NS-2 simulation parameters.

Parameter	Value
Area of sensor field	1200 m × 1200 m
Number of sensor nodes	150
Radio range of a sensor node	200 m
Propagation model	Two-Ray ground
Transmit power	0.660 W
Receive power	0.395 W
Transmission range	45 m
Node placement	Random
Traffic type	CBR (UDP)
Packet size	64 bytes
Number of BS	1
MAC protocol	MAC/802.11

4.2. Simulation Results and Discussion. In Figure 4(a), it can be observed that PCCDC outperforms PASCC when packet drop is considered. Even though PCCDC and PASCC adopt cluster based network topology PCCDC performs better than PASCC. Since PCCDC handles intra- and interlevel congestion separately and also each node is designed with an appropriate queue model, packet drop is reduced considerably. The packet loss in PCCDC is 42.02 percent lower than PASCC. Packet drop and packet delivery ratio are inversely proportional. Figure 4(b) demonstrates the average packet delivery ratio of random mobility model. The reduced packet loss in PCCDC results in higher packet delivery ratio of 13.62 percent over PASCC protocol.

Generally the network scales up due to dynamic environment, the number of congested nodes also increases, and in addition control packets exchanged to contain congestion considerably increase. But in PCCDC routing protocol, intercluster communication requires control packets for routing whereas intracluster communication uses linear feedback nodes that proactively listen to packets. As a result the control overhead PCCDC is 17.91 percent lower than PASCC as shown in Figure 4(c).

In cluster based protocols end-to-end delay depends on relative location between CMs and BS and the resource allocation of CHs as well. Increase in end-to-end delay is quite inevitable when the number of congested nodes increases in the network, since PCCDC protocol uses the differentiated queue model for CM and CH to reduce the end-to-end delay for real-time packets. Figure 4(d) compares the end-to-end delay between PCCDC and PASCC. It can be understood that end-to-end delay in PCCDC is 5.07 percent less than PASCC.

Control overhead has significant effect on residual energy. In short, reduced control overhead stands for reduced residual energy which is shown in Figure 4(e). Residual energy in a node is highly determined by the energy consumed in sensing events, receiving and sending sensed data packets, and transmission of control packets. In PCCDC, the flooding sensors remain in the sleep mode until the temperature sensor exceeds threshold. Once the temperature sensor exceeds threshold, then the transmitter of flooding sensor is turned on. Until the real-time event gets detected, sensor nodes remain in the sleep mode. When the node's queue length exceeds the upper threshold, then temperature sensor also enters into sleep mode. PCCDC utilizes the limited energy of the nodes efficiently compared with PASCC. This results in 18.03% lesser residual energy in PCCDC with respect to PASCC.

The simulation was performed with 0.5 J of initial energy to calculate the network lifetime. Life time of a network is closely associated with energy consumption contributed by the protocols. If more energy is consumed the sensor nodes drain out and the network may scale down. The condition further deteriorates when congestion results in packet drop and retransmission of packets. PASCC does not choose optimal path of CHs based on the congestion estimate and hence congested CHs can easily drain out. This in turn imparts negative impact on network life time with PASCC when compared to PCCDC. Figure 4(f) shows that PCCDC results enhanced life time of 5.62% when compared to PASCC.

4.3. Theoretical Analysis

4.3.1. Energy Consumption. Energy consumption can be defined as the average energy consumed by each node during the given simulation time and is expressed in Joules (J). The energy model of a PCCDC protocol for WSN is different from energy consumption model proposed in the literature [28]. In PCCDC protocol the energy consumption for sensing, receiving, and updating for a packet size k in bits is the same for both CM and CH node but it is different during transmission. Hence the total energy consumption of a CH node differs from that of a CM node which is derived below.

First consider the energy required for sensing a single bit in CM and CH node. It is given by

$$E_{\text{sensing}} = e_i * p, \tag{3}$$

where e_i = energy consumption of a node when sensing single bit and p = payload of the sensed data.

The energy required for communicating is primarily due to the transceiver of the node. The two main components of a transceiver are radio electronics and power amplifier.

Generally the energy consumption in radio electronics for the packet size k in bits is given by

$$E_{\text{radio\_electronics}} = kE_{\text{radio}}. \tag{4}$$

Also the energy consumption in power amplifier depends on the distance between transmitter and receiver. If the distance between the transmitter and receiver is less than the crossover distance d_{cross} then the propagation is inversely proportional to d^2 where the f_{riss} free space model is used; otherwise propagation is inversely proportional to d^4 where two-ray ground propagation model is used. The crossover distance is obtained using

$$d_{\text{cross}} = \sqrt{\frac{E_{\text{free\_space}}}{E_{\text{two\_ray}}}}. \tag{5}$$

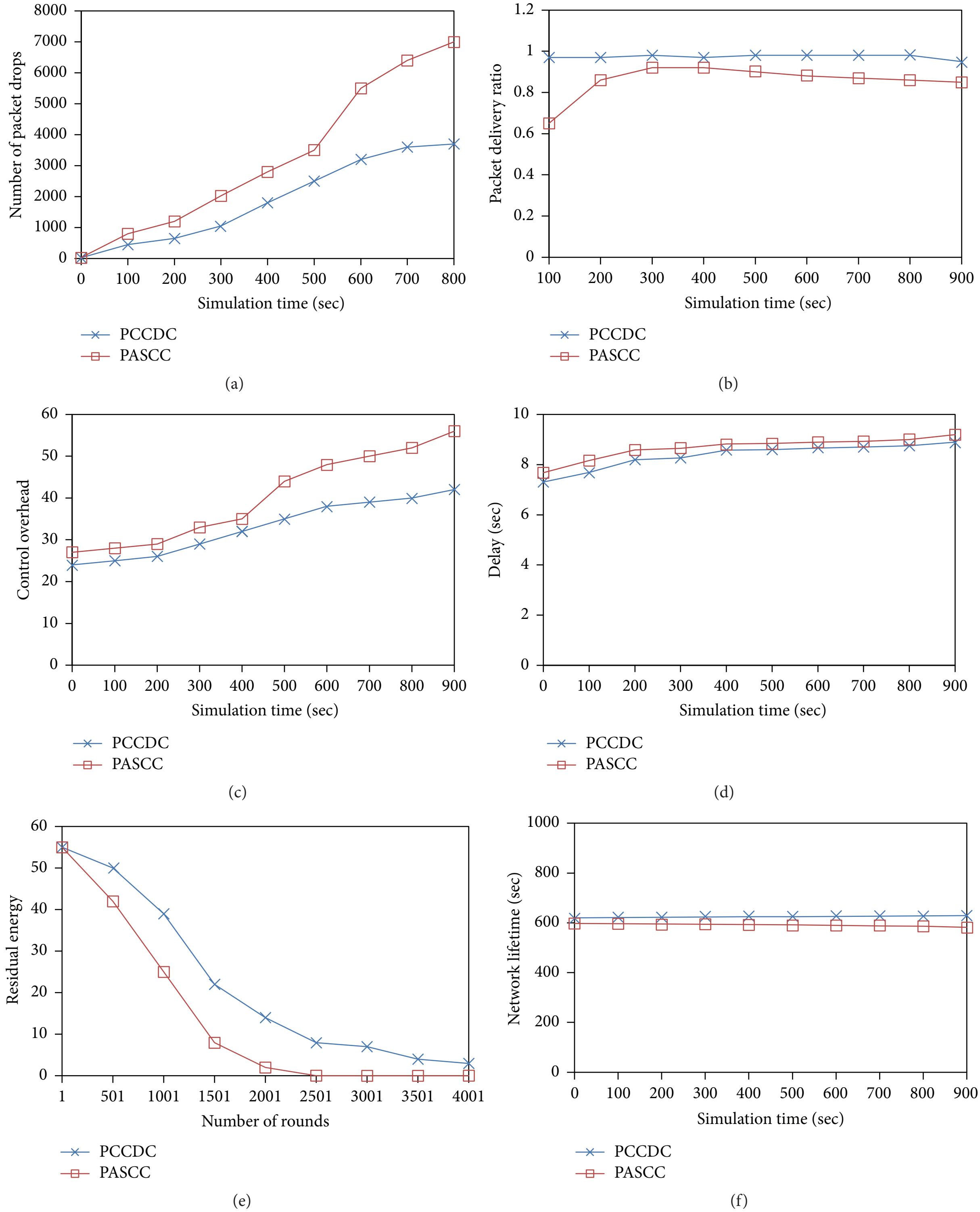

FIGURE 4: Performance comparison of PCCDC and PASCC protocol against simulation time.

The energy consumption in power amplifier for the packet size k in bits is given by

$$E_{\text{power\_amplifier}} = \begin{cases} kE_{\text{free\_space}}d^2, & d < d_{\text{cross}} \\ kE_{\text{two\_ray}}d^4, & d \geq d_{\text{cross}}. \end{cases} \quad (6)$$

The distance d from CM to CH can be calculated by received signal strength indicator (RSSI). It is given in

$$d = 10^{|\text{RSSI}-A|/dx}, \quad (7)$$

where A is the received signal strength at the position which is 1 m away from the sending point. RSSI is the received signal strength indication, and x is the factor of path fading, which is generally 2 to 5.

Hence the energy required for transmitting the packet size k in bits for CM node is calculated by

$$E_{\mathrm{TX}}(k,d) = E_{\text{radio\_electronics}} + E_{\text{power\_amplifier}}$$

$$E_{\mathrm{TX}}(k,d) = \begin{cases} kE_{\text{TX\_radio}} + kE_{\text{free\_space}}d^2, & d < d_{\text{cross}} \\ kE_{\text{TX\_radio}} + kE_{\text{two\_ray}}d^4, & d \geq d_{\text{cross}}. \end{cases} \quad (8)$$

Due to the additional data aggregation operation and long distance transmission, the energy consumption of CH is more than its CM. Therefore the energy required for both transmission and data aggregation for the packet size k in bits only in CH is obtained using

$$E_{\mathrm{TX}}(k,d) = \begin{cases} nkE_{\text{TX\_radio}} + kE_{\text{free\_space}}d^2 + nkE_{\text{agg}}, & d < d_{\text{cross}} \\ nkE_{\text{TX\_radio}} + kE_{\text{two\_ray}}d^4 + nkE_{\text{agg}}, & d \geq d_{\text{cross}}, \end{cases} \quad (9)$$

where n is the number of CMs associated with each cluster which is given in

$$n = \frac{N}{k_{\text{optimal}}}, \quad (10)$$

where N is the total number of nodes in a WSN. k_{optimal} is the optimal number of clusters in each round. E_{agg} is energy consumption during data aggregation operation of CH.

But the energy required for receiving the packet size k in bits for both CM and CH node is the same which can be calculated using

$$E_{\mathrm{RX}}(k,d) = E_{\text{RX\_radio}} * k. \quad (11)$$

Similarly the energy required for update packet size k in bits for both CM and CH node is calculated using

$$E_u(k,d) = E_{U\text{\_radio}} * k. \quad (12)$$

Therefore the total energy spent of a node N_i is the summation of energy consumptions during sensing, transmitting, receiving, and updating the packet size k in bits could be calculated by

$$E_s(N_i) = E_{\mathrm{TX}}(k,d) + E_{\mathrm{RX}}(k,d) + E_u(k,d). \quad (13)$$

The energy needed for routing packets depends on the residual energy at the node N_i is $E_r(N_i)$. Initially the energy present in the node is assumed to be 1. Energy spent for routing a packet is $E_s(N_i)$. Therefore the residual energy at node $E_r(N_i)$ is computed in

$$E_r(N_i) = 1 - E_s(N_i). \quad (14)$$

5. Conclusion

The proposed PCCDC protocol provides complete coverage and connectivity using mobile nodes. To reduce energy consumption, nodes are organized into clusters. PCCDC clusters have two phases, namely, setup and data transmission phase. PCCDC assigns priority to real-time packets; the number of real-time packets getting dropped during congestion is reduced considerably because PCCDC handles congestion at both intra- and intercluster level separately. An appropriate queue model in CM and CH also avoids packet drop due to congestion.

In PCCDC real-time packets are captured after non-real-time packets exceed the threshold limit. This reduces the number of real-time packets being generated. Since real-time packets are time stamped, they are transmitted immediately to BS to provide higher packet delivery ratio. PCCDC also maintains coverage fidelity to ensure that packets coming from far off nodes and with more sense value are delivered immediately to avoid getting dropped. The number of control packets needed in PCCDC is much lower due to binary feedback at intercluster level thereby reducing the energy consumption which in turn increases the network lifetime. The proposed PCCDC is compared with PASCC protocols.

The proposed protocol reduces the energy consumption but at the same time incurs a slight time delay due to dynamic clustering during emergency situations. To address this time delay, it is proposed to handle the data transmission phase of PCCDC in two different situations. During normal situation CHs alone participate in data transmission to BS and under critical situation data can be transmitted through a minimum number of nodes which are surrounding the event.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Proactive Alleviation Procedure to Handle Black Hole Attack and Its Version

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The world is moving towards a new realm of computing such as Internet of Things. The Internet of Things, however, envisions connecting almost all objects within the world to the Internet by recognizing them as smart objects. In doing so, the existing networks which include wired, wireless, and ad hoc networks should be utilized. Moreover, apart from other networks, the ad hoc network is full of security challenges. For instance, the MANET (mobile ad hoc network) is susceptible to various attacks in which the black hole attacks and its versions do serious damage to the entire MANET infrastructure. The severity of this attack increases, when the compromised MANET nodes work in cooperation with each other to make a cooperative black hole attack. Therefore this paper proposes an alleviation procedure which consists of timely mandate procedure, hole detection algorithm, and sensitive guard procedure to detect the maliciously behaving nodes. It has been observed that the proposed procedure is cost-effective and ensures QoS guarantee by assuring resource availability thus making the MANET appropriate for Internet of Things.

1. Introduction

Earlier communication technique was Human to Human (H2H) which gradually turned into Human to Machine (H2M), and now it took a wider leap into the Machine to Machine (M2M) communication called Internet of Things (IoT) [1]. IoT is the scenario, where all the devices in the network are no longer computers but "things." Things would include cars, home automation sensors, surveillance cameras [2], containers in cargo, and trucks on transit. IoT paradigm proposes to connect all physical objects in a global Internet-based infrastructure to exchange information and communication. IoT aims to support intelligent identification, location, tracking, monitoring, and management. IoT is therefore based upon the integration of several communication solutions, identification and tracking technologies, sensor and actuator networks, and distributed smart object [3, 4]. IoT promises a smart environment that would offer immense savings of time, energy, and resources. For example, in real time world, the IoT scenario applied for smart homes appliances like refrigerators, air conditioner, and some other electronic goods is controlled by the mobile communication. This was the suitable example for the IoT scenario which will work based on the following concepts.

Figure 1 declares the wireless sensor network architecture with regard to space and distributed autonomous sensors to monitor environmental conditions on the space, something just mentioned like pressure, sound, temperature, and so on. The WSN is built with many nodes; maybe it is varied from several hundred, where each node is connected to one sensor (or sometimes several sensors). All those nodes are working for sensors only. WSNs are an area monitoring application. WSN is deployed over a region, where any state is to be monitored.

IoT is the concept where the future environment will be surrounded by smart objects with interdependent networks of smart communication protocols such as Mobile Network Protocols of GSM and GPRS and IP Multimedia Subsystem

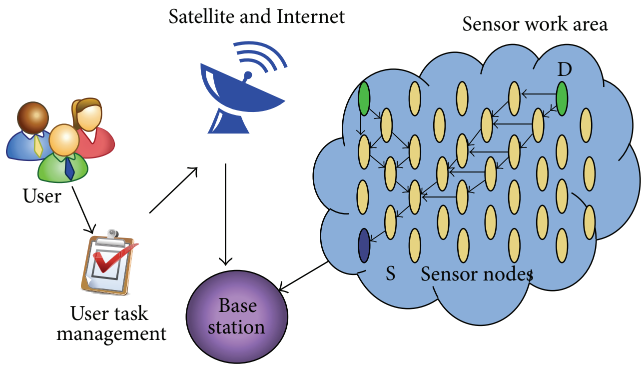

Figure 1: Wireless sensor network architecture.

Protocols and Communication Services, smart homes such as smart homes appliances like refrigerators, air conditioners, and water heaters, smart traffic such as GPS navigation rear-view mirror [2], smart city such as surveillance camera based observation of a person or group of places, and smart health such as patient online surveillance system and artificial human part artifact that has been created by someone or some process in medical domain. Enormous number of services will be made available to interact with these "smart objects" like sensor, and so forth. These objects are used in internet for sending a query, changing their state and conveying the information associated with them. While taking all this into account, security and privacy issues are going to be very huge. It thus creates a world where the physical objects are perfectly integrated into the information network and where the physical objects can become active participants in areas like business processes, life critical applications, and so forth.

Moreover, from the technical point of view, the basic idea behind this concept is the ubiquitous presence of a variety of things or objects such as radio-frequency identification (RFID) tags, sensors, actuators, and mobile phones. These objects are able to interact with each other and cooperate with their neighbors through unique addressing schemes like Session Management, Multimedia Services over IP Networks, Time Synchronization and Network Mobility [5]. World Wide Web (a merger of networks and databases) [6] was heavily used around the network users. IoT has more schematic domains; particularly wireless sensor networks [7] and ad hoc networks are two main preliminary domains. Therefore, the biggest challenge in this integral part of the future Internet is the caliber of utilizing the existing technology like wired and wireless communication. The realm of IoT cannot exist without the help of ad hoc network [4].

For instance, the objects should communicate with each other, whether an infrastructure exists or not. IoT increasingly involves a number of sensitive systems that will have to be protected immensely. Thus securing IoT especially sensor network is vital. However, the usage of the "smart objects" in wireless communication and ad hoc networks focus on the tremendous security challenges. These challenges alters the communication between two parties, which makes them unsecure. Attacking neighbor sensing protocols like SYN attack, UDP attack and authentication server attack spoils the transport layer session and provides hijacking [8] for unauthorized TCP session.

Among those attacks of packages data into IP datagrams, the network layer attacks like black hole attack, wormhole attack, rushing attack, sinkhole attack, and gray hole attack are more serious; particularly black hole attack in networking is more vulnerable whose underlying idea is to inject them in the active path from source to destination or to absorb the network traffic. As an experiment, the versions of black hole attack are massive threat to IoT, since it has the potential to distrust the entire network of IoT objects or part of the network, whose participation is essential to carry out the mission-critical and time-critical applications. Disrupting the IoT network [4] may result in serious consequences like loss of life, revenue, property, and so forth.

2. Related Works

Wireless sensor network (WSN) and ad hoc networks are prone to several serious security issues like network layer attacks. Thus wireless sensor network, its integration into IoT, and the various security challenges are discussed as follows.

2.1. Wireless Sensor Networks. A wireless sensor network is a collection of autonomous nodes distributed spatially over a network, where each node is connected to two or more locations for the purpose of transmitting and receiving data with respect to the sensors [9] concisely used for communicating any medium in wireless domain. The key functions of WSN are broadcast and multicast, routing, forwarding, and route maintenance. Each of such sensor network nodes has several hardware components like a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, a power source, usually a battery, and so forth. The topology of the WSN can vary from a simple star network to a complex wireless mesh network. Applications of WSN are wider, like immense use in military applications such as ocean surveillance systems, battle field surveillance, and attaching microsensors to weapons for stockpile surveillance [10]. The abovementioned applications joined together into a whole of wireless sensor networks that are divided into three categories [9], namely, monitoring objects which include monitoring both living and nonliving objects, monitoring space, and monitoring the interactions between objects and space.

The first category monitoring objects can be exemplified by structural monitoring. It is possible to detect the mechanical impact like breakages of the structure by acoustic emissions, sensing the vibration modes, responses to stimuli, and so forth, on the structure of buildings [11], bridges [12], and so forth. Environmental monitoring is the best example for monitoring space. In environments like forests [9], mountains [13], and glaciers [10], WSNs are deployed for the purpose of gathering environmental factors for long period of time. Also other environmental details such as temperature, humidity, moisture, and light sensor readings help in observing the environment. The combination of first and second category led to the third category monitoring interaction between objects and space. This comprises monitoring threats such as volcanic activities [14] and floods [15].

The last category deals with monitoring human beings. For example, in wearable computer jackets, the installed sensors would gather physiological information like heart beat rate, blood pressure, diagnosing patients with bipolar disorder [16], and also observing the patients in home care scenario [17]. Thus WSN applications have broadened its horizon in different fields. As WSN is one of the most important elements in the IoT, the benefits of connecting WSN and IoT [9] elements go beyond remote access, as heterogeneous information systems can be connected collaboratively to provide common services (new). It is important to consider the suitable approaches for the integration of WSN into the Internet. Wireless networks can be either infrastructure based networks or infrastructure less networks. In infrastructure based networks, communicating mobile devices are controlled and coordinated by base stations, whereas in infrastructure less networks, no centralized control point is present. Ad hoc networks fall under the category of infrastructure less networks. Security and privacy are the main issues in wireless networks [13]. If attackers exist, they can carry on a wide variety of attacks on the routing algorithm including selective forwarding, black hole, rushing, resource depletion, worm hole, and Denial of Service attacks.

Unfortunately, almost all wireless network routing algorithms are vulnerable to these attacks [13]. Moreover the various types of attacks are reduced based on many research articles; particularly Deng et al. studied the routing security issues and also analyzed black hole attack [12], where the problems are easily employed against the MANETs and they proposed solution for the same problem through AODV routing protocol. Thus we propose the new article for careful consideration to the black hole attack and reduce the same attacks on the WSN and ad hoc networks.

Panicker and Jisha proposed various attacks [8] in the MANET, particularly in network layer especially black hole attack, which is reduced by three mechanisms like TOGBAD, SAR protocol, and DPRAODV protocol [18] based reduction. It has some cons like protocol functionality, route distance, and network overload. To overcome this drawback, we introduced the new approach for hole detection algorithm to detect the maliciously behaving nodes and produce the cost-effective and ensure QoS guarantee by proactive alleviation procedure.

2.2. Ad Hoc Networks. In ad hoc networks, the nodes work in cooperation with each other in managing the network. In addition to acting as hosts, the nodes should also act as routers during the transmission. MANET is an ad hoc network, where the nodes are mobile in nature, cooperating with each other in network management, without the use of a network infrastructure or any centralized administration [13]. The primary goal of a MANET routing protocol is to establish a correct and efficient route between a pair of nodes, so that messages may be delivered in a timely manner.

Wu et al. proposed survey on attacks and countermeasures in MANET to achieve security goals, such as access control, authentication, availability, confidentiality, integrity, and nonrepudiation [19]. It also provides the MANET-IDS (Intrusion Detection Systems) to prevent attacks. Through this survey, we analyze the various ad hoc networks countermeasures in terms of packet delivery ratio and QoS guarantee such as network support, availability, and time consumption of the specific nodes on the networks.

Bhattacharyya et al. proposed DATA traffic attacks and CONTROL traffic attacks [20] to preserve the networks with respect to the RREQ and RREP methods. Thus network layer DATA traffic attacks are reduced by the proactive alleviation procedure.

Gagandeep and Kumar proposed [21] and discussed the various types of attacks under protocol stack and routing. Security issues associated with mobile ad hoc network attacks were classified based on the active and passive attacks. In particular, the active attacks like timing attacks are reduced based on the rushing attacks against on-demand routing protocols. These procedures are helpful to us to reduce the timing attacks like the ad hoc networks.

2.3. Integration of WSN and the Internet. Wide range of various sensor network applications, network embedded sensing or controlling devices were constructed by different databases, hardware platforms, and middleware and operating systems. To design the architecture of sensor, most application environments of sensor network are designed in tightly coupled closed architectures. From numerous advanced monitoring and control applications, wireless sensor networks [9] connect with the Internet by Tiny TCP/IP implementation, spatial IP address assignment, shared context header compression, application overlay networking, and distributed TCP caching. Thus we propose the following approaches for connecting the WSN to the Internet based on three methods: independent network, hybrid network, and access point network [22]. Since most of the WSNs access the Internet, both independent WSN and the internet can be connected through a single gateway. This falls under the first approach which is illustrated in Figure 2. A WSN can be completely independent of the Internet (front-end), be able to exchange information with Internet hosts (gateway), or share a compatible network layer protocol (TCP/IP).

As there is a dramatic increase in the integration, the second approach has come into existence. In Figure 3, the level

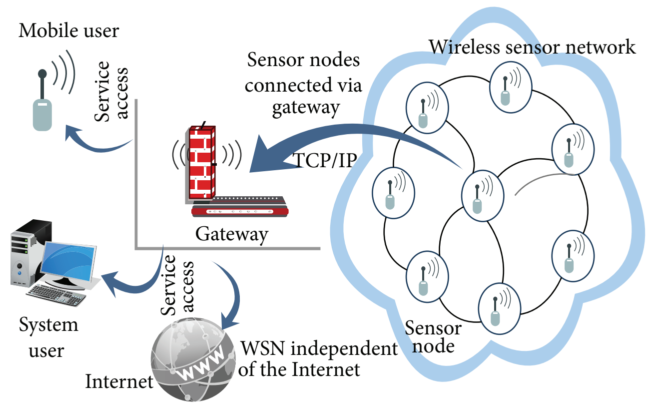

FIGURE 2: Independent networks.

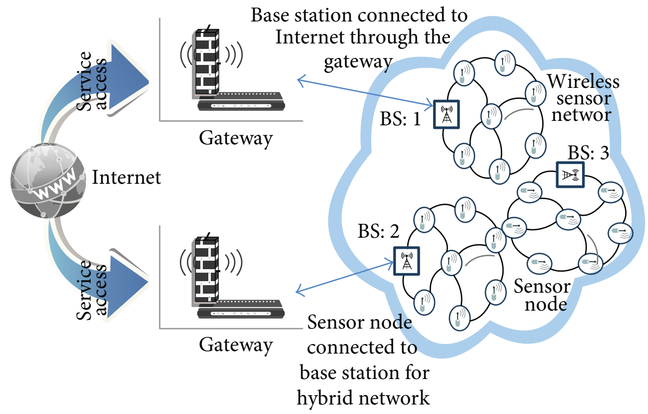

FIGURE 3: Hybrid networks.

of integration of both the independent networks depends on the actual location of the nodes, which provides access to the Internet. These nodes can be a few dual sensor nodes (e.g., base stations) located on the root of the WSN (hybrid).

Figure 4 illustrates the third approach, which is the current WLAN structure that forms an access point network. This network allows the sensing nodes to access the Internet in one hop (access point).

The access point approach is also called the TCP/IP solution. The sensor nodes implement the TCP/IP stack; thus they can be considered as the complete backbone of the Internet. Any Internet host can open a direct connection with them, and vice versa. Moreover, this solution fully integrates the WSN with the IoT [9].

2.4. Challenges in Integrating WSN and the Internet. The potential tasks to be accomplished by the sensor nodes are network configuration, Quality of Service, and security [23].

2.4.1. Network Configuration. Network configuration based on wireless medium is processed by the identification of premises and correct wireless driver availability and also configuration of interface on the sensor network. Afterwards choose managing wireless connections wireless management tools. Particularly sensor nodes are also required to control the WSN configuration, which covers various tasks, like ensuring scalable network constructions, ensuring self-healing capabilities by detecting and eliminating faulty nodes, and also managing their own configuration. However in order to achieve better caliber of the network and its operations, means of network configuration and management is necessary.

2.4.2. Quality of Service. The Quality of Service which includes the average delay, lifetime of node, throughput, switching delay, and mobile and multiple sinks is of greater importance to WSN topology. To improve service management in terms of IoT, the gateways act only as repeaters and protocol translators. Sensor nodes should ensure the Quality of Service through optimum utilization of resources of all the devices that take part in IoT. With respect to balancing of workload between the nodes that offer available resources, it is necessary to improve the QoS for mechanisms that require high amount of resources like security mechanisms. Since rapid changes in the link characteristics of the nodes can lead to considerable reconfiguration of the WSN topology, it is very essential to find new approaches to ensure service guarantees.

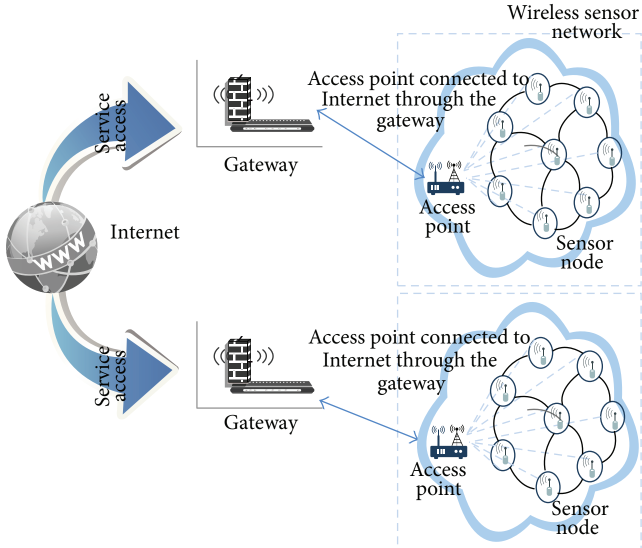

FIGURE 4: Access point networks.

2.4.3. Security. Commonly in WSNs, the sensor nodes play an important role in ensuring data confidentiality, integrity, availability, and authentication depending on the sensitivity of the application. However, the scenarios for an attack need to present physically almost near the targeted WSN, in order to collapse the network by introducing malicious nodes. Thus when WSNs openly access the Internet, such nearness in the location will no more be required and attackers would be able to threaten WSNs from everywhere. Therefore, novel security mechanisms must be developed with the resource constraints in concern to protect WSNs from the attacks originating from the Internet.

2.5. Security Challenges. While WSNs are the essential part of the IoT, several security challenges are also under consideration. It is essential to consider the security of the IoT from a global perspective rather than an issue that is related to a particular technology. As discussed previously, TCP/IP solution is the best solution to effectively integrate WSN and the Internet. However, there are multiple factors to be considered, in order to choose the suitable integration approach [new]. The main factors are summarized below.

2.5.1. Resilience. Any WSN that directly provides its services to external entities is quite vulnerable to attacks. For example, it is very easy to launch a Denial of Service (DoS) attack due to the throughput of the transmission medium and the capabilities of the sensor nodes. Thus gateways and sensor nodes must comprise security mechanisms against such attacks.

2.5.2. User Authentication and Authorization. Every node in a network might not be scalable for long-lived applications; thus it is necessary to consider the implementation of single sign-on systems like Kerberos to authenticate and authorize the user [17].

2.5.3. Security of the Communication Channel. It is considered that IPsec might be too “heavy” for constrained WSN [22]. Therefore, it is necessary to analyze other mechanisms such as TLS to offer an end-to-end secure channel. In fact, it is also necessary to study the different key exchange mechanisms that should be used in this context.

2.5.4. Accountability. For an Internet-enabled WSN, it is essential to develop a distributed system that is able to record the interactions with the users of the system. By storing all interactions, we are able to recreate security incidents and abnormal situations.

2.5.5. Functionality. In some applications, the sensor nodes do not need to be aware of the Internet. For example, while the tasks of WSN are limited to collecting information and answering users’ queries, it is not necessary to contact any Internet service.

2.5.6. Hardware. A specially constrained sensor node might not be able to directly connect to the Internet due to the memory requirements of the different security mechanisms (e.g., AES-128, Elliptic Curve Cryptography) and the Internet protocols and standards (e.g., HTTP, web services).

2.5.7. Inherent Weaknesses. Internet-enabled sensor nodes are vulnerable to many different types of attacks, ranging from DoS attacks to exploit attacks. This particular factor is actually quite important in choosing whether certain applications should completely isolate their sensor nodes from the Internet, filtering all traffic at the edge of the network.

2.5.8. Network Redundancy. A group of sensor nodes may offer the same functionality for redundancy purposes. But in a TCP/IP environment, an external host will request services from specific nodes through their IP addresses. Thus it is necessary to develop specific mechanisms in TCP/IP environments to deal with exceptional circumstances (e.g., unreachable nodes).

2.5.9. Protocol Optimization. Most WSN-specific protocols include certain mechanisms that allow a network to self-heal and to optimize its internal behavior.

3. Attacks in WSN and Ad Hoc Networks

3.1. Wormhole Attack. There are two unauthorized parities which interrupt and communicate on the network which are called wormhole attack. From wormhole attack, an attacker receives packets at one point in the network, "tunnels" them to another point in the network, and then replays them into the network from that point [24]. Routing can be disrupted, when routing control messages are tunneled. This tunnel between two colluding attackers is referred to as a wormhole. Packet leashes are used to combat wormhole attacks.

3.2. Sinkhole Attack. Sinkhole is a more complex attack [22] compared with black hole attack. Given certain knowledge of the routing protocol in use, the attacker tries to attract the traffic from a particular region through it. Other nodes will then consider the path through this attacker node better than the currently used one and move their traffic onto it. Since affected nodes depend on the attacker for their communication, the sinkhole attack can make other attacks like gray hole, black hole, and so forth.

3.3. Rushing Attack. Two colluded attackers use the tunnel procedure to form a wormhole. If a fast transmission exists between the two ends of the wormhole, the tunneled packets can propagate faster than those through a normal multihop route. This is called the rushing attack [17]. The rushing attack can act as an effective DoS attack.

3.4. Gray Hole Attack. Gray hole attack has two phases. In the first phase, a malicious node exploits the AODV protocol to advertise itself as having a valid route to a destination node, with the intention of intercepting packets, even though the route is spurious. In the second phase, the node drops the intercepted packets with a certain probability. In this gray hole attack, routing misbehavior leads to dropping of messages packets selectively. These will be rectified by secure signature algorithm to trace the packet dropping nodes on ad hoc network. Gray hole attack is a variation of black hole attack in which the normal node will suddenly behave maliciously and start dropping packets selectively. Thus detecting this kind of attack is more challenging [25].

3.5. Black Hole Attack. Clearly MANET and WSN are vulnerable to various attacks. Attacks in the network layer have two purposes: not forwarding the packets or modifying some parameters of routing messages. A basic attack that an adversary can execute is to stop forwarding the data packets. A black hole attack is a kind of Denial of Service, where a malicious node sends a forge reply to the source node that it possesses a shortest route to the destination. The source will establish a connection by forwarding packets to the adversary. The adversary in turn will discard those packets without forwarding them to the destination. Cooperative black hole attack is an attack where multiple black hole nodes perform in coordination.

In [11], it is emphasized that, in order to ensure the security between two communicating nodes, a protocol must enable the destination node to identify the source of a given message, and the source node must be able to authenticate the legal destination node. The work done in [15] presents a reputation-based routing scheme for hierarchical ad hoc networks and the cluster head, acting as the reputation manager for updating reputation information. Thus, the malicious nodes would be isolated for safeguard routing security. In [14], a secure routing protocol with payment mechanism that prevents node selfishness for mobile ad hoc networks is proposed. A source node can securely send a confidential message to the destination node through a number of intermediate nodes. In addition, all messages transmitted between nodes should be verified and protected in the protocol.

In [26], anti-black hole mechanism is discussed. Every node is subjected to an estimation of the suspicious value. The suspicious value is found based on the amount of abnormality in RREQ and RREP packets of the node. When the suspicious value exceeds a threshold value, the node is identified as a black hole and the Intrusion Detection System (IDS) will blacklist the node and the time of identification. Thus the cooperative black hole nodes can be identified. The drawback is that the mobile nodes have to maintain training data and regular updates.

In [27], CBDAODV mechanism is proposed. A source node will accept at least two RREP packets from different replying nodes. Thus by utilizing another routing path, the source node itself can evaluate the reliability of the currently selected route and make a rerouting decision once it suspects the reliability of currently selected route. Through another route, a confirmation control packet which consists of the name of the second malicious node to which the first malicious node sends the data packets is sent. On receiving the packet, the destination node will reply to indicate the existence of the route between the destination and the malicious node. If the reply packet indicates that no path exists, the source node now switches its routing path to the alternate route and retransmits its data packets. Also the malicious nodes are put to observation, to identify whether the nodes regularly work in cooperation with each other.

In [28], a solution is proposed by modifying the AODV protocol to avoid multiple black holes in the group. It maintains a fidelity table. Every participating node is given a fidelity level that tells the reliability of that node. Any node having value as 0 is considered as malicious node and is eliminated from the network. The fidelity levels of the nodes along a route are increased on every successful transmission of the data; otherwise the fidelity level of the nodes is decreased. The processing delay in the network is high.

In [29], MOSAODV mechanism is presented, where a timer is set in the source node to collect all the RREP packets and those packets with exponentially high destination sequence number are discarded. In [29], all the RREPs are stored in the newly created table, until the modified wait timer. The modified wait timer is initialized to be half the value of RREP wait time, which is the time for which source node waits for RREP control messages before regenerating RREQ. The source node after receiving first RREP control message waits for modified wait time. For this time, the source node will save all the coming RREP control messages in the new table. Subsequently, the source node analyses all the stored RREPs from the new table and discards the RREP having very high destination sequence number. The node that sent this RREP is suspected to be the malicious node. Once such malicious node is identified, it can discard any control messages coming from that node. Now since malicious node is identified, the routing table for that node is not maintained.

In [30], DPRAODV mechanism is proposed to encounter black hole attacks in AODV. In normal AODV, the node that receives the RREP packet first checks the value of sequence number in its routing table. The RREP packet is accepted, if it has RREP_seq_no higher than the one in routing table. In the proposed mechanism, an additional check is performed to find whether the RREP_seq_no is higher than the threshold value or not. The threshold value is dynamically updated as in [13] in every time interval. As the value of RREP_seq_no is found to be higher than the threshold value, the node is suspected to be malicious and it adds the node to the blacklist. As the node detects an anomaly, it sends a new control packet ALARM to its neighbors. The ALARM packet has the blacklist node as a parameter, so that the neighboring nodes know that RREP packet from the node is to be discarded. Thus the malicious node is isolated from the network by the ALARM packet. The threshold value is the average of the difference of dest_seq_no in each time slot between the sequence number in the routing table and the RREP packet. In this mechanism, the threshold of a valid RREP sequence number is derived dynamically to evaluate the sequence numbers of the received RREP packets for every route request.

In [18], a mechanism is proposed to defend cooperative black hole attack. Each node observes the data forwarding nature of its neighboring node. This information is recorded in a DRI (Data Routing Information) table. Each node maintains an additional DRI table. In the DRI table, 1 stands for "true" and 0 for "false." The first bit stands for information on routing data packet from the node, while the second bit stands for information on routing data packet through the node. If the entry is 0 for a node N implies that a node has not routed any data packets from or through N. An additional cross-checking method is also done. The source node broadcasts a RREQ message to discover a secure route to the destination node. The intermediate node (IN) generating the RREP has to provide its next hop node (NHN) and its DRI entry for the NHN. Upon receiving RREP message from IN, the source node will check its own DRI table to see whether IN is a reliable node or not.

4. Proposed Proactive Black Hole Alleviation System

The proposed black hole alleviation system adopts a mechanism that would proactively detect the black hole nodes and isolates them in order to ensure a secure communication.

The various notations used in the proposed system are tabulated along with the description as follows:

a_1: source node,

a_n: destination node,

a_i: intermediate node, where $i = 2, 3, \ldots, n-1$,

$\{p_1, p_2, \ldots, p_n\}$: possible nodes between a_i, and a_{i+1}

g_i: geographical region, where $i = 1, 2, \ldots, n$,

t: time in minutes,

$\{D_1, D_2, \ldots, D_n\}$: monitoring units for regions $\{g_1, g_2, \ldots, g_n\}$,

s: time in minutes or seconds.

During transmission, the data originated from the source node is forwarded by the intermediate nodes and finally reaches the destination. However from one node to another node, there should exist 1 to n paths in the direction towards the destination. If no path exists, it means there are no objects, or it may be the result of black hole attack.

From source a_1 to destination a_2, there exists the increment of a_i nodes. For a_1 to a_2, there may exist p_1 to p_n (possible nodes in the path to become a_2). After fixing up a_2, for a_2 to a_3 there may be p_1 to p_n. At every node, there exist p_1 to p_n alternatives. Therefore any a_i in the path from a_1 to a_n is the outcome of $\{p_1, p_2, \ldots, p_n\}$.

Moreover, each and every node in the path a_1 to a_n is geographically distanced. Therefore in this task, the nodes from the same geographical region for every set $\{p_1, p_2, \ldots, p_n\}$ are considered as a cluster g_i. The nodes form closed knowledge sharing networks at various geographical levels which gives a structure to identify the black hole like attacks:

For $(i = 1; a_i \leq a_n; i + 1)$

if $(n > 3)$ \\ where "n" is the number of possible nodes

there exist a region $g_i = \{p_1, p_2, \ldots, p_n\}$

else if $(n < 3)$

there does not exist a region g_i

trigger Hole detection Procedure

while $(n \geq 1)$.

Therefore, single active node present in that region $\{p_1, p_2, \ldots, p_n\}$ is enough to uphold the route path through that region. If a_1 is in g_1 (similarly a_n is in g_n), then the geographical region is constituted at least with the minimum of three nodes. If there does not exist a geographical region, then a single active node in that region $\{p_1, p_2, \ldots, p_n\}$ can uphold the route path through that region. The challenge is to keep at least one node in the geographical region active to accomplish the mission. However the attacks like worm hole, black hole, and so forth have the potential to completely disrupt the network of nodes in a single geographical region or more, thus leaving the network unoperational. Therefore to detect the black hole attack, two methods are proposed here. If the path between a_1 and a_n is mission critical, then the following algorithm should be implemented. The following procedures are useful to make the proposed methodology concise against the black hole data centric attack in MANET and wireless sensor network.

4.1. Timely Mandate Procedure. Timely updating of the node status is done from the monitoring units based on the availability requirements. Set of $\{g_1, g_2, \ldots, g_n\}$ may be connected to single or more monitoring units. Monitoring units may be data collecting point or nearby server, and so forth. One is timely updating of the node status to the monitoring units. This monitoring is designed based on the requirement for a specific application to take place. For instance, a health of the person is monitored from the remote place by the doctor; in that case he may collect 1 sample a day or 2 or more samples a day based on the health condition of the patient. The time is scheduled by the doctor. Consider $\{g_1, g_2, \ldots, g_n\}$ connects a_1 to a_n. If data is collected at every t, then nodes in the region $\{g_1, g_2, \ldots, g_n\}$ are scheduled to respond to $\{D_1, D_2, \ldots, D_n\}$ in $(t - s)$ seconds earlier, respectively. At any D_i, if the status of any a_i in any g_i is not updated before $(t - s)$ seconds, then the node is considered unavailable.

4.2. Hole Detection Procedure. This algorithm is triggered based on untimely reply, on element of doubt, or on special cases, and so forth. If a black hole intends to steal only the data packets, then it will not obstruct the routing process; this includes path discovery. If the black hole does not obstruct the routing, then the existing techniques can be fooled. Therefore, the hole detection algorithm transmits the data packets and carefully records the status of the acknowledgement. However, the hole detection algorithm randomly generates the message and broadcasts the message to the next hop.

The first few data bits are considered as flags. The flags are as follows:

Resource (R): if the packet is sent as a message this flag is set to “1.”

Warning (W): if this flag is set to “1” then it serves as warnings about certain nodes being a black hole component.

Acknowledgment (A): if this flag is set to “1” the received packet is an acknowledgement.

Power (P): the status of power is mentioned.

Unique nonce (N): number used only once in the communication and generated by a separate formula by each and every node, where i is the serial number of the node $\{1, 2, \ldots, n\}$.

Unique ID (I): since no standard naming convention exists for sensor nodes this 16-bit number is unique to each and every sensor.

Geographical serial number (G): this number contains two octets and is written in the form $(g \cdot n)$, where g is the region number and n is the serial number of that node.

In the data packet, the following details are placed $\{R\|P\|N\|I\|G\}$: if R is present then it is an enquiry, and it should be acknowledged. The remaining portion of the data packet is dumped with the random messages and then broadcasted to the next hop. Those who receive the enquiry packet after verifying it will acknowledge the sender with $\{A\|P\|N\|I\|G\}$. In case, if a node is compromised, it will not send the reply or send the irrelevant reply. Based on that the sender after being timed out by the next hop or through getting the irrelevant reply warns the other nodes in the region g_i with the notification message $\{A\|N_S\|I_S\|G\|I_i\}$ called black hole intimation packet, where the suffix marks the source node. Suffix “i” marks the ID of the suspected node as being black hole.

4.3. Sensitivity Guard Procedure. The sensitive geographical region is one where the possibility of attack is high. For instance, the nodes deployed to monitor the movements of enemies [12], and so forth. To monitor the attack, complex security procedures as proposed for path discovery and path reversal can be used [24]. Moreover the public key algorithm RSA is used, since it gives better performance over other public key encryption schemes [16]. Since the sender of the data needs to be authenticated, RSA digital signature scheme is applied to the enquiry packet with $\{R\|P\|N\|I\|G\}$, the acknowledgement packet $\{A\|P\|N\|I\|G\}$, and the black hole intimation packet $\{A\|N_S\|I_S\|G\|I_i\}$. However before using the public key certification, the data packet is padded with OAEP. After the padding is done, the message is encrypted with the private key of the sender which will then be decrypted by the receiver with the public key of the sender.

5. Result Analysis

Many datasets relevant to wireless sensor networks are collected from various providers like I-LENSE software and datasets, and so forth. After collecting the dataset, the attack conditions for black hole, wormhole, and so forth are applied in the dataset. Various algorithms are analyzed by applying the methods to the generated dataset. The result is presented in Table 1.

The analysis shows the irregular vulnerabilities that the existing methods have towards the black hole attack or to the version of black hole attack. This is an important analysis because it clearly proves that even the secure methods can be victimized by the version of black hole attack. Therefore, in the future if the ad hoc network is used for IoT, it will exhibit weakness towards this type of attacks. Hence it becomes highly risky for the mission-critical applications to function on the IoT. Various countermeasures are analyzed against the attacks and the result is presented in Table 2.

However, interestingly there are countermeasures, which have the potential to detect and mitigate one or few attacks but not all types of attacks. Moreover, many countermeasures are of reactive [31] type. This causes a slump in performance for some time period. This results in packet loss and delay in

Table 1: Vulnerability analysis of routing protocols.

Attacks	Countermeasure	Effectiveness
Black hole	SAR	Effective
Wormhole	Packet leashes	Effective
Rushing attack	RAP	Versatile
Resource Depletion	IDS	Effective
Gray hole	Checkpoint based multihop ACK	Versatile
Sinkhole	Intruder detection	Versatile
DoS	IPS/IDS	Versatile

Effective: avoids or allows negligible damage.
Versatile: allows attack only to do a partial damage.
Ineffective: allows the attack to meet out considerable or full damage.

Table 2: Effectiveness of attack countermeasures.

Attacks	AODV	DSR	SAODV	ARAN	ARIADNE	SEAD	SAR
Black hole	V	PV	V	V	V	V	NV
Wormhole	V	PV	V	V	V	V	V
Rushing attack	V	V	NV	NV	NV	NV	V
Resource depletion	V	V	V	V	V	NV	NV
Gray hole	V	V	PV	PV	NV	V	NV
Sinkhole	V	V	V	V	V	V	V
DoS	V	V	V	V	NV	NV	V

V: vulnerable.
PV: partially vulnerable.
NV: not vulnerable.

packet transmission, which is not tolerable in mission-critical applications.

According to Figures 5 and 6, it is evident that supporting the WSN infrastructure with necessary components rather than just implementing more countermeasures and security features yields better result. It is because those detection methods are costly and they consume a considerable amount of time to recover the system from the attack, which in turn will impact on the system performance. It makes the environment futile for mission-critical applications.

Figures 7 and 8 show the results obtained based on experimentation on dataset 3. From Figure 7, a considerable amount of drop in percentage of packet delivery could be found, when there are multiple black hole attacks. The attacks are encountered with the countermeasures; however the countermeasures are not instantaneous. Thus there is a potential drop in the network performance as soon as attack is introduced. But time-critical applications cannot stand this nature. Thus the proposed alleviation procedure proves its proactive behavior that prevents the delayed detection of the attack, ultimately thwarting the drop in the packet delivery.

The Quality of Service guarantee of the network is analyzed in Figure 8. The network that adopts the alleviation procedure provides at least a minimum of QoS guarantee that keeps the network working, where the launch of an attack is immaterial. The throughput analysis is shown in

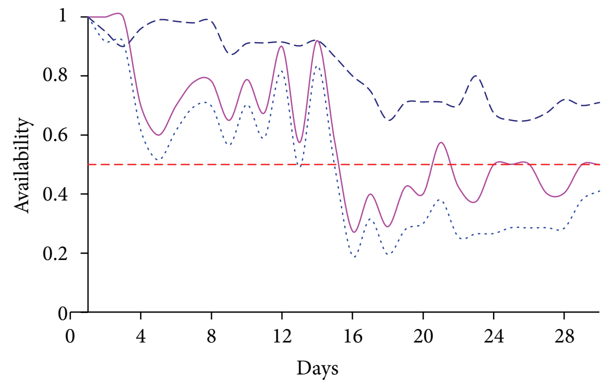

Figure 5: Measure of availability on dataset 1 with and without various detection procedures, where dotted blue line marks the detection with 2 methods and magenta line marks the detection with 3 methods, where dark blue line marks the detection with alleviation procedure.

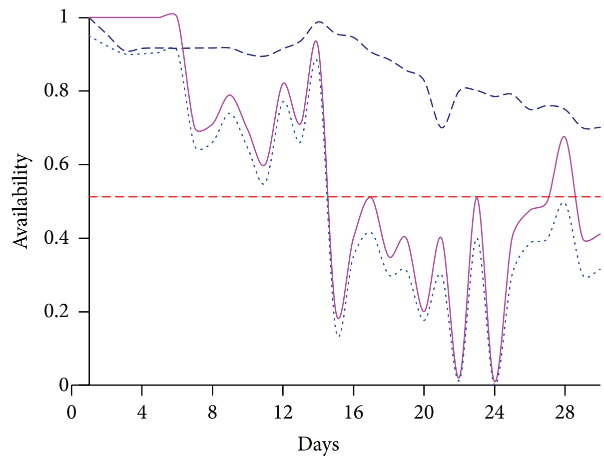

Figure 6: Measure of availability on dataset 2 with and without various detection procedures, where dotted blue line marks the detection with 2 methods and magenta line marks the detection with 3 methods, where dark blue line marks the detection with alleviation procedure.

Figure 9. The throughput significantly increases with respect to time, without any descent at any point in the network. Thus the timely monitoring of the environment and categorizing the environment based on regions and identifying sensitive regions, as well as ensuring security for critical regions more importantly ensuring minimum provisions, made the alleviation procedure unique and good enough to support the mission-critical applications.

6. Conclusion

IoT is used for future Internet user. But if the Internet user uses IoT effectively, there are many sets of facts that arise on the IoT. Consequently, the existing infrastructure which includes even the resource and power constrained WSN and ad hoc networks should adapt to the needs of the IoT to support various types of services. When we reduce those

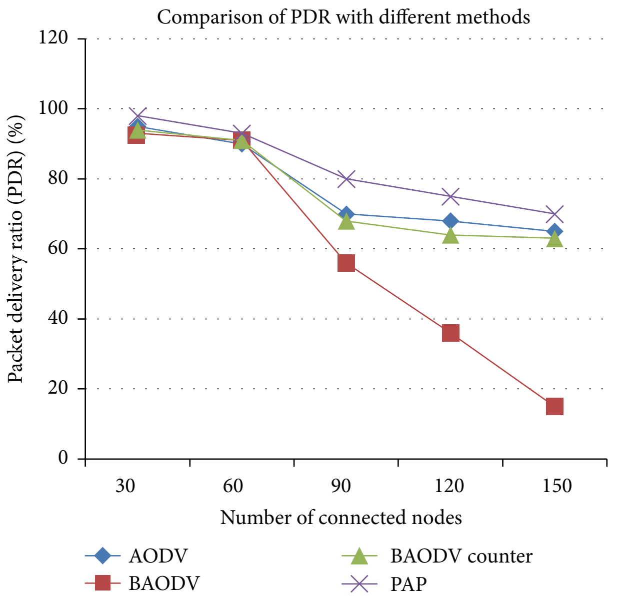

Figure 7: Measure of packet delivery ratio on dataset 3 with no attack, with black hole attack, with other countermeasures, and with the proactive alleviation procedure.

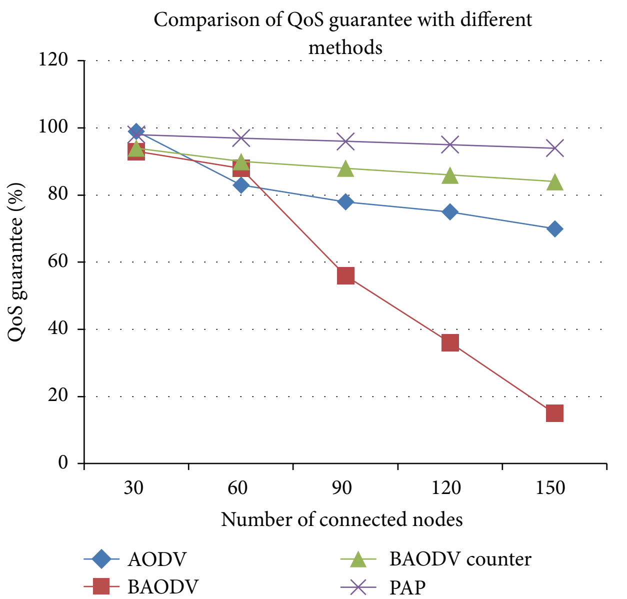

Figure 8: Measure of QoS guarantee on dataset 3 with no attack, with black hole attack, with other countermeasures, and with the proactive alleviation procedure.

constraints like unauthorized data and control centric attack, IP configurations loss, and the environmental compatibility, the user faces number of various restrictions. From those restrictions, the most annoying thing is the data centric attack named black hole attack and its version. To solve this issue, we propose an architecture level solution to sustain the network to support the array of applications. To solve this issue, we propose an architecture level solution to sustain the network to support the array of applications. Thus the results

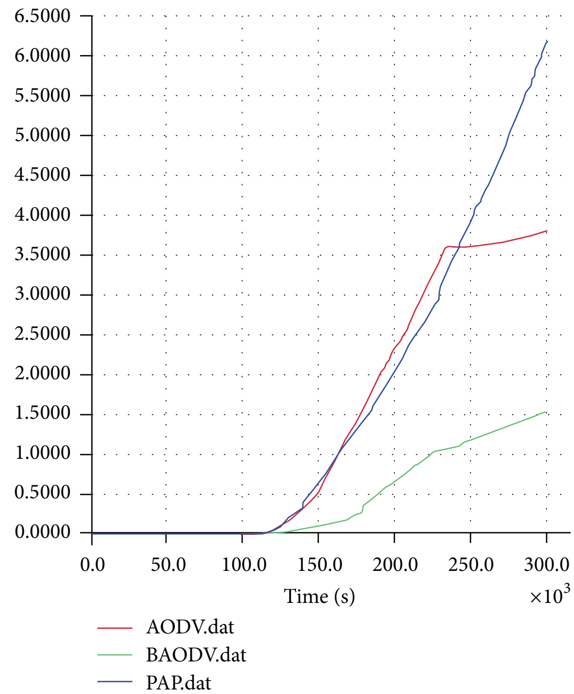

Figure 9: Measure of throughput on dataset 3 with no attack, with black hole attack, and with proactive alleviation procedure.

of proactive alleviation procedure to handle black hole attack and its version's proposed algorithm prove better solution for black hole attack and its upcoming versions.

In the developing era of ad hoc networking and wireless sensor networks, many updated technologies are available. There are many technologies like microelectromechanical systems technology, digital electronics, and potential sensor networks applications which are applied for the IoT. In addition to that our proposed method applies many domain applications like environmental/earth sensing, industrial monitoring, entertainment industry, and so on.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Framing a Knowledge Base for a Legal Expert System Dealing with Indeterminate Concepts

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Despite decades of development of formal tools for modelling legal knowledge and reasoning, the creation of a fully fledged legal decision support system remains challenging. Among those challenges, such system requires an enormous amount of commonsense knowledge to derive legal expertise. This paper describes the development of a negotiation decision support system (the Parenting Plan Support System or PPSS) to support parents in drafting an agreement (the *parenting plan*) for the exercise of parental custody of minor children after a divorce is granted. The main objective here is to discuss problems of framing an intuitively appealing and computationally efficient knowledge base that can adequately represent the indeterminate legal concept of the well-being of the child in the context of continental legal culture and of Polish law in particular. In addition to commonsense reasoning, interpretation of such a concept demands both legal expertise and significant professional knowledge from other domains.

1. Introduction

From their inception, expert systems have been seen as a suitable tool for decision support in legal contexts [1, 2]. However, while the first attempts to create such systems seemed promising [3], deeper inquiry revealed a number of difficulties [4]. While it is not our concern here to elaborate the problems associated with the representation of legal knowledge in computer systems, it is our opinion that the most difficult task in that context is to model the commonsense knowledge and contextual reasoning mechanisms widely used by legal practitioners. Without such elements, expert systems could only be used to support decisions in the most trivial cases. A few important aspects of the modelling of commonsense knowledge in legal decision support systems are worthy of further discussion here: the modelling of indeterminate concepts widely used in legal practice and the representation of commonsense rules reflecting the mode of reasoning used by human lawyers. It is trivial to observe that commonsense rules differ from strict, logic-based rules in that they are, for instance, usually defeasible, uncertain, and sometimes conflicting. The nature of such rules and the relations between them has long been a topic of debate ([5, 6] and many others).

Among many and varied previous conceptions of legal decision support tools ([3, 7] and others), we will focus here on one specific approach in developing a tool to support negotiation between parents in drafting a plan for parental custody arrangements for minor children following a divorce. In particular, the present paper describes our attempt to formalise currently informal mechanisms for evaluation of a child's well-being, which requires some discussion of salient aspects of the formalisation of legal and commonsense knowledge. Appropriate utilisation of various forms of negation as well as determination of orders between rules is crucial for the accuracy of models of knowledge. The main objective here is to discuss how an intuitively appealing and computationally efficient knowledge base can be framed to deal with such indeterminate legal concepts and how the preference relations between rules used to interpret this concept in concrete cases can be determined.

The present investigation is structured as follows. Section 2 outlines the structure of the Parenting Plan Support System (PPSS). Section 3 compares PPSS with existing online dispute resolution systems (mainly those dealing with issues of family law) and details the research problem here. Section 4 considers the possibility of generalising features of individual cases from a practical legal perspective, referring mainly to civil law culture, where, in principle, there are no binding precedents or derived argumentative schemes. In Section 5, the notion of heuristics as understood in cognitive science is discussed, as well as the kinds of move used in the AI and law literature to establish preference relations between the elements of relevant knowledge bases. Section 6 presents a technical discussion of the syntax of defeasible rules—that is, the possibility of utilisation of negation in their antecedents—and discusses the notion of preference between rules. Finally, Section 7 presents our conclusions.

2. The Parenting Plan Support System

PPSS [8–10], partially implemented in [11], is a negotiation decision support system to support parents in drafting an agreement (the *parenting plan*) to govern their exercise of parental custody over minor children after a divorce is granted under Polish law.

2.1. The Parenting Plan: Legal and Conceptual Context. In a divorce judgment, the Polish family court determines parental authority over a minor child and parties' contact with the child, and issues regarding the financial costs of maintenance and raising the child are decided. The court recognises such an agreement between the spouses only if it is consistent with the "well-being of the child." The court may grant parental authority to only one of the parents, confining the other parent to specified duties and rights in respect of the child. Alternatively, provided they have submitted a parenting plan, the court may grant parental authority to both parents, on the assumption that they will cooperate on matters regarding the child (art. 58 §1 and 1a of the Polish Family and Custody Code, hereafter PFCC). A similar regulation is applicable in the case of unmarried parents living separately (art. 107 PFCC). In abstract terms, Polish law does not favour any specific allocation of parental authority; the issue is always decided on the concrete circumstances of a case. In this context, it is important to note the constitutional and statutory principle of the autonomy of parental authority in Polish law (art. 48 par. 1, art. 53 par. 3, and art. 70 par. 3 of the Polish Constitution and art. 97 §1 PFCC).

The fundamental issues of relevance to the parenting plan as agreed by the parents (sometimes with participation of a third person such as a mediator) are parental authority, contact between parents and child, and the child's well-being. These in turn relate to "background" concepts such as public interest, the interests of the parents, and the rational cooperation of parents and child. According to Polish law, parental authority is to be defined as the duty and right of the parents to have custody over the person and property of the child, with due regard to the child's dignity and rights. Children subordinate to parental authority owe obedience to their parents, and even where the children are competent enough to act independently, they should take into account their parents' advice, provided that this advice is formulated for the sake of the child's well-being. Parental authority should be exercised in accordance with the child's well-being and with public well-being, and any reasonable wishes of the child should be taken into account under certain conditions (art. 95 PFCC). The parents must raise and direct the child under their parental authority, taking care of the child's physical and spiritual development and preparing him or her to work as a member of society in accordance with his or her abilities. The child remains under parental authority until reaching legal maturity, typically at 18 years of age. In principle, parental authority is vested in both parents (art 92 and 93 PFCC). Independent of parental authority, both parents and child have the right and duty to remain in contact. This contact with the child encompasses, inter alia, spending time with the child, direct communication, and distance communication (e.g., by means of electronic devices) (art 113 PFCC).

Parental authority should be exercised in accordance with the child's well-being, in the public interest (95 §3 PFCC) and with respect to the dignity and rights of the child as specified in the UN Convention on the Rights of the Child (adopted on 20 November 1989). In consequence, the child's well-being should be considered central and prerequisite in the exercise of parental authority and contact between the parties. This is determined in light of the concrete circumstances of a given case to ensure the proper personal (spiritual) development of the child (Order of the Polish Supreme Court 11 January 2000, I CKN 327/98). The concept of the child's well-being relates to the concept of the prevailing interest of the child, construed on the basis of the UN Convention on the Rights of the Child (Preamble to the Convention).

The second major criterion is the public interest. The child's upbringing is also a realisation of the parents' social function, taking care of the child's physical and spiritual development to prepare him or her to work for the benefit of the society, according to his or her capacities (art. 96 §1 PFCC). The Convention also takes into account these matters, albeit with important caveats (cf. the Convention and the Resolution of the PSC of 12 June 1992, III CZP 48/92).

As a consequence, in deciding on the issue of parental authority, the court should be guided first and foremost by the child's well-being (with due regard to the public interest) rather than solely or mainly by the interests of one or both parents (cf. Resolution of the PSC of 12 June 1992, III CZP 48/92, and Judgment of the PSC of 25 August 1981, III CRN 155/81). The interests of the parents remain important but cannot be decisive; the court should, if possible, take into account the position and interests of the parents (Order of the PSC of 5 May 2000, II CKN 765/00, and Resolution of the PSC of 09 June 1976, III CZP 46/75). This approach is consistent with the Convention on the Rights of the Child (cf. Resolution of the PSC of 12 June 1992, III CZP 48/92, and Resolution of the PSC of 08 March 2006, III CZP 98/05). The principle of rational cooperation between parents and child must also inform the exercise of parental authority (cf. art. 72 par. 3 of the Polish Constitution, art. 95 §2 and 4 of the PFCC).

Summarising the legal and conceptual context in which the parenting plan is developed, the following points should be noted:

(1) If the divorcing parents (or unmarried parents living apart) intend that parental authority be vested in both of them, they should prepare an agreement (the parenting plan) governing their exercise of parental authority and contact with the child.

(2) The plan is assessed by the court, principally on the criterion of the child's well-being and with reasonable expectations of parental cooperation with regard to the child. However, the court must also take into account other criteria, including the public interest and the interests of the parents.

(3) The plan is in principle adopted as a particular type of agreement rather than as a formal settlement and does not entail any substantive legal results. Instead, the plan is no more than a premise to be taken into account by the court in order to vest parental authority in both of the parents. The court alone is authorised to decide on the rules governing the exercise of parental authority, and the plan is not binding on the court.

(4) The plan is approved by means of a judgment granting parental authority to both parents. In cases where the plan is not accepted the court decides on matters of parental authority, based on the totality of the case's circumstances and taking into account any proposals submitted by the parents in the plan.

(5) Polish law does not prescribe any particular form or content for the parenting plan.

The legal context for the decision support system described in this paper involves rules of law that prescribe no ready answers to issues arising in drafting a parenting plan. Presumably, no uniquely "right" plan exists in any concrete situation, and this legal domain can certainly be characterised as ill-defined [12]. The system described here aims to revisit the domain to provide interested parties with a tool that may be of use in resolving problems that arise in drafting the parenting plan.

2.2. The Parenting Plan Support System: Functional and Structural Context. In preparing a parenting plan, the task for parents is to devise an agreement that can satisfy judicial assessment of whether it ensures the child's well-being (as interpreted in the concrete circumstances) and of whether it can reasonably be expected to be realised. More specifically, the functions of such a plan are as follows:

(i) To facilitate regulation of relations between parents and child following divorce.

(ii) To secure the child's interests.

(iii) To eliminate any unacceptable behaviour of the parents.

(iv) To educate the parents with regard to pedagogical, legal, psychological, and social principles informing their relations with the child.

(v) To prevent future judicial disputes concerning the child's well-being.

It is worth noting that this task is made more difficult because the parents are in conflict and are not usually professionally equipped to draft a parenting plan.

In determining the content of a parenting plan, the argumentative discourse exhibits four main dimensions: communicational, informational, relational, and decisional. The preferred negotiation strategy is nonadversarial and cooperative, characterised by a win-win paradigm as against an adversarial, win-lose competitive approach. The final version of PPSS should provide the following support for parents in performing these tasks:

(1) Providing the parties with a template of sufficient complexity for the parenting plan, adjustable to the concrete circumstances of a case and with a simple tutoring module that sets out the functions and aims of the system.

(2) Enabling users to input salient data concerning the child and relations between parents and child, as well as other relevant data.

(3) Including information about the nature of any conflict between the parents and, in particular, whether that conflict relates to the parents' respective values.

(4) Providing the parents with a rich variety of (contextually relevant) options to clarify the scope and limits of their choice.

(5) Encouraging the parents to adopt a cooperative attitude by providing suggestions concerning their choices and possible mutual concessions.

(6) Enabling the negotiating parents to communicate, allowing them to deliberate directly on some choices while opting for automated generation of other parts of the plan.

(7) Establishing the space of agreement concerning contextual data provided by the parents, enabling negotiation of options that are mutually acceptable and mutually advantageous and realistic.

(8) Grounding any suggestions provided by the system (and ultimately by the negotiated parenting plan) in an interdisciplinary knowledge base encompassing psychological, pedagogical, and legal data.

(9) Assessing any options chosen by the parents in terms of the child's well-being, in a way that predicts the likely judicial assessment of the plan.

(10) Generating a final electronic version of the parenting plan to be submitted to the court. The system should also be able to update the plan where future circumstances change.

This paper is concerned with the system's conceptual architecture rather than its technological aspects. Although the system has not as yet been fully implemented, some initial attempts have been made [11]. An important subset of the system's knowledge base has been extracted from thirty actual and influential judgments by the Polish Supreme Court, yielding a large number of salient factors that will play a crucial role in the operation of the system, as detailed below. A case analysis based on an existing (unofficial) sample form of the parenting plan made it possible to systematise the content of the parenting plan into ten parts, referred to as "categories." Additional special categories—relating, for instance, to any incapacities of the child—are omitted here. For each parenting plan, data referred to as *Essential Information* must be entered. For the sake of simplicity, we assume here that the parents have only one child. On that basis, the structure of the parenting plan is as follows.

Essential information:

(i) Formal (data relating to the parties, important dates, etc.),

(ii) emotional (relating to emotional relations between the actors involved),

(iii) implementation (declarations relating to realisation of the agreement after its execution).

The specific parts of the plan are structured as follows (more detailed discussion is presented in [8]):

Category 1: contact between parents and the child.

Category 2: contact between the child, family members, and other people.

Category 3: education.

Category 4: livelihood.

Category 5: leisure, holidays, and ceremonies.

Category 6: worldview and childrearing rules.

Category 7: child health.

Category 8: information and documentation.

Category 9: proceeding in emergency cases.

Category 10: any other issues.

The list of categories (i.e., issues to be included in the parenting plan for completeness) is based on informal templates for such agreements that are used in actual practice. The structure of the agreement is mirrored in the knowledge representation structures of PPSS.

2.3. Structure of PPSS. PPSS consists principally of the following modules:

(i) The Questionnaire asks users to provide basic information about their situation (e.g., age and number of children, income, and familial relationships). The system suggests answers, but no NLP support is offered in the present version. As a result, data relating to the so-called *Environmental Factors* are stored in the system. These propositional elements are essential to contextualise the assessment of options chosen by users in the next module.

(ii) The Option Choice Module presents proposals to users relating to contractual clauses to be incorporated in the parenting plan. Most importantly, the system assesses any options chosen by users in terms of the well-being of the child. Such assessment is made possible by the rule-based inference engine, which takes as input the Environmental Factors introduced by users and the options they choose, generating an evaluation of these options as output. This part of the system has been partially implemented [11]. The development of this module is of central interest here.

(iii) The Option Deliberation Module enables users to compare the options they have chosen and to enter into a bargaining phase. If users can agree on a set of contractual provisions, PPSS generates an agreement (i.e., a parenting plan) as an output. This part of PPSS exists only as a theoretical model (see [8, 9] for a detailed description), and work is in progress on its implementation. The functioning of this module is not central to the present contribution.

(iv) The Explanation Module is a standard component of expert systems, providing users with reasons for system inferences and outputs.

One important element of the Option Choice Module is a rule-based expert system for interpretation of the concept of well-being of the child. This part of the system is of utmost importance because, under Polish law, the parenting plan can be accepted by the court only if that plan accords with the criterion of well-being of the child. One of the main functions of the system is to indicate to users whether the provisions of their chosen agreement are in accordance with this criterion, which remain an indeterminate concept. The relevant literature identifies several types of indeterminateness of legal concepts [13]: *open-textured* (where the emergence of new situations in the world may change its initial boundaries); *contextual* (where the meaning and scope of the concept change with context); and *evaluative* (where investigations concerning meaning and scope of legal concepts meaning and scope depend significantly on the individual evaluations of the agents involved). This indeterminateness raises the question of how a concept of this type can be modelled in an expert system. One obvious requirement is that the system's knowledge base should include a set of exemplary cases, explaining both prototypical and borderline instances of the concept's application. This is perfectly embodied in the Case-Based Reasoning (CBR) approach in the AI and law literature, which emerged in the USA in the 1980s and has continued to evolve [14–16], leading to the development of hybrid systems that combine rule-based and case-based elements [17]. Another important line of development relates to the introduction of elements of teleological reasoning into the knowledge base [18–20]. Although fruitful, these ideas are not directly applicable to legal expert systems rooted in continental legal culture (as opposed to common law culture), where there is no doctrine of binding precedent, and judges—who often take a formalistic approach—are not inclined to engage in discussion of the values underlying their decisions.

The PPSS knowledge base (presented in detail in [9]) encompasses, in particular, the following elements.

Options. These include any propositions that may form part of the parenting plan. Options are grouped under Questions, each of which provides for a set of options. The assumption is that, in any developed agreement, one and only one Option from each Question should be chosen.

Dimensions. PPSS contains a library of ten dimensions, each related to one of the important broad issues (categories) that inform the content of any parenting plan. More detailed lists of the dimensions can be found in [9, 11]. Each dimension comprises a ten-step ordinal scale [0–9] (from least favourable to most acceptable with respect to the well-being of the child).

Environmental Factors (EFs). This set encompasses sentences containing basic information about people involved in the dispute, as well as a basic description of the case. Users generate a concrete set of EFs by making choices in the Questionnaire module of PPSS.

Defeasible Rules (DRs). As a generalised account of DRs (modified with respect to the earlier view presented in [9, 11]), let DR(Di) be a set of defeasible rules assigned to a Dimension i. A rule belongs to this set if and only if it has the following form:

$$\Omega \Longrightarrow [0 \leq n \leq 9]\,(Di)\,, \tag{1}$$

where

(i) Ω is a finite conjunctive formula encompassing elements from the set of options and EFs such that the set of options includes at least one element (the set of EFs may be empty);

(ii) $[0 \leq n \leq 9](Di)$ is the valuation of the antecedent of the DR in question with regard to one of the dimensions of PPSS.

Defeasible rules are not rules in the traditional meaning of this word (see, e.g., [6, 21]), nor are they (valuation) functions because of their defeasibility. They are conditionals, in which satisfaction of antecedents does not entail truthfulness of a conclusion but establishes the level of estimation of a given dimension. In other words, DRs adopt conjunctions of options and EFs as their input and generate a value from the ten-step ordinal scale as their output. It follows that the set of defeasible rules within PPSS may be defined as a set of relations adopting elements from the power set of the set of all propositional elements (options and EFs) in the knowledge base (PROP) as its domain and the elements of the set of values (V) encompassing the ten elements (from 0 to 9) as its codomain:

$$\mathrm{DR} = R\left\langle p \in P\,(\mathrm{PROP})\,, v \in V\right\rangle. \tag{2}$$

Additionally, we define a preference relation for the set of rules (see Section 6 for a formal exposition). If two rules, r_1 and r_2, belong to the relation of preference, and r_1 is preferred over r_2, then, where both are applicable to a given factual situation, the consequent of r_1 is derived and the consequent of r_2 should be rejected. On that basis, the evaluation of a given option can be performed in the following way.

For every option, a set of defeasible rules should be chosen whose conditions are satisfied by a given case. If such set is empty, the evaluation of that option cannot be performed; if there is one rule, that rule becomes the preferred one; if there is more than one rule, the preferred one should be chosen on the basis of the order ORD. If preferred rules are chosen for all options, the option attracting the highest level of evaluation for a given dimension is optimal. Where users opt for other solutions, they are informed of the suboptimal character of their choice.

Forming the most important part of the Option Choice Module, the inference engine operating on a knowledge base generates assessments for users about the options they have chosen in terms of its value for the well-being of the child. As understood by the Polish judiciary and in the literature on pedagogy and developmental psychology, this is considered paramount. As explained in [10], users may react in different ways to valuations provided by the system's inference engine; that is, they may agree or disagree with the information provided by PPSS. In cases of disagreement with the system's suggestions, users may be asked to provide grounds for their position by choosing one of the possible answers suggested by the system. If the information provided by PPSS is assessed as irrelevant by users (e.g., because the contextual information stored in the knowledge base is insufficient to grasp the actualities of the case), they may engage in communication with each other by means of a dialogue panel. The information provided by this module is important for the process of negotiation because it informs the parties about available alternatives to the negotiated agreement.

Once sets of options have been chosen, parents may move to the next module of the system: the Option Deliberation Module (ODM). Described in [8, 9], this module has not yet been implemented but exists as a theoretical model. The ODM enables users to check whether the options they have chosen are within their space of agreement and to enter into a bargaining phase. The system enables both manual and semiautomated allocation of options, and users are asked to assign numerals to the disputed options (the sum of the points assigned by each user is normalised to 100). PPSS favors those allocations that maximise the equality of distribution of preferred options among users, once they do not violate the value of well-being of the child. The eventual output of the system is a proposal characterised by complete parental agreement.

3. Comparison of PPSS to Related Work and Formulation of Research Problem

As outlined in the preceding section, PPSS is an online dispute resolution (ODR) model that integrates three artificial intelligence techniques: NDSS (Negotiation Decision Support Systems), RbS (Rule-based Systems), and CBR (Case-Based Reasoning) (see [22] for a general discussion of the application of AI techniques in ODR systems). With regard to the latter two components, PPSS acts as a classic expert system, providing answers for users of the system concerning the acceptability of their chosen parenting plan provisions in terms of the indeterminate criterion of the child's well-being. In order to define the scope of the contribution of the PPSS project, it is necessary to compare it to existing work in the field.

The first important comparison is provided by work in the field of Negotiation Support Systems. In the domain of family law, the systems developed by Zeleznikow and his collaborators, such as Family_Winner [23], Asset Divider [24], and IMODRE [25], came to prominence in the relevant literature. The PPSS Option Deliberation Module (still a theoretical model) performs functions similar to those of the well-known Family_Winner program. This latter system is well known, assisting mediators and parties in family disputes concerning the allocation of certain important items, both monetary and nonmonetary (such as custody of the child). Family_Winner uses game theory and heuristics to generate tradeoff maps, representing a party's preferences and tradeoffs. Items to be divided are entered by the users themselves; the values that are taken into account in the process of negotiations reflect the interests and preferences of the negotiating parties. As noted by Abrahams et al. [25], this facet of Family_Winner has been discussed with representatives of Victoria Legal Aid in Australia, and it was suggested that the authors should incorporate the notion of fairness in their further work, reflecting the paramount interest of children. Inter alia, this led to the creation of the Asset Divider program and a full-fledged multiagent system called IMODRE, in which an Asset Divider-based agent serves as one among many cooperating artificial agents.

It is clear that the line of development of such systems proceeds from the classic Negotiation Support Systems paradigm to incorporate elements of legal knowledge. The point of departure for PPSS was exactly the opposite, structuring the legal knowledge base relating to interpretation of the concept of the well-being of children (similar to the paramount interest of children in Australian family law) and leaving the implementation of the NDSS module of the system for future research. PPSS does not generally allow users to name issues or items negotiated; instead, it requires parties to reflect on all the important clauses of the potential parental agreement. Such a methodological choice has serious consequences; it is noted in the literature that Family_Winner and Asset Divider are, to a large extent, domain-independent [23, 26] while PPSS is obviously strictly domain-dependent, as Environmental Factors, options, and defeasible rules will be inapplicable to other domains of negotiation.

Given that the current work on PPSS focuses on the RbS and CBR components rather than on the NSS, more detailed comparison with existing solutions is not possible. It is worth noting, however, that PPSS embodies the desiderata for ODR environments as formulated by Lodder and Zeleznikow [27], who suggest that such systems should be able to perform the following functions:

(i) Calculating best alternatives to negotiated agreements (BATNAs) for the parties.

(ii) Enabling the parties to communicate with each other to discuss disputed issues in a process of dialogue.

(iii) Proposing how disputed items are to be allocated among the parties.

Calculation of BATNAs and of other types of alternatives to negotiated agreements such as WATNAs (worst alternatives to negotiated agreement) and MLATNAs (most likely alternatives to negotiated agreement) is among the most important topics in the development of NSS and ODR tools in general (see, e.g., [28]). PPSS, which offers users an assessment of their chosen options in relation to the legal criterion of well-being of the child, advises divorcing parents of how their preferred clauses are likely to be assessed by the court and of the clauses that would be probably favoured by the court. The presence of certain environmental factors may also play a role in predicting judicial rulings in cases of lack of agreement between spouses; for instance, where there has been a history of violence towards the child by one of the users, it is highly likely that their parental authority will be limited or even refused.

As indicated, PPSS enables users to communicate with each other. However, this is not the most important feature of the system, as it focuses on a legal assessment of parents' preferred options more than on satisfaction of those preferences. As noted earlier, PPSS also provides a module for allocation of the discussed items (options). While the desiderata formulated by Lodder and Zeleznikow are met, PPSS places strong emphasis on legal assessment of the deliberated agreement rather than on mechanisms to support realisation of parties' interests.

The output generated by PPSS might be interpreted as advice for the involved parties or mediators. In this respect, it may be compared to Split-Up (see, e.g., [29]), a well-known decision support system used in family law cases involving the division of marital property. An important difference between PPSS and Split-Up is that while the latter is a hybrid system, combining rule-based mechanisms and connectionist networks, PPSS exclusively uses traditional symbolic propositional representations. This choice is dictated by the educational function of PPSS, requiring that all steps of inference performed by the program should be explicable to the users to persuade them to follow partial items of advice, leading eventually to the final output. Such functions cannot be performed by subsymbolic connectionist representations, which can however perform very fine-grained inferences, thus providing adequate advice or accurate prediction. Here, however, the aim is to explore the potential of classical hybrid systems rather than the application of other technologies to the problem.

On that basis, the most important comparators for the PPSS project are the classical CBR and hybrid systems that use representations based on dimensions and/or factors [14, 16, 17, 30, 31], as well as recent developments in the field of ODR that make extensive use of CBR inference mechanisms [32]. It should first be emphasised that the account of dimensions employed in PPSS differs significantly from the classical account presented in the HYPO system [16]. Briefly, HYPO dimensions are complex knowledge representation structures used to index cases and build arguments for or against the disputant's interest. These dimensions range from extremely proplaintiff to extremely prodefendant. They enable the system to retrieve cases similar to the case at issue (with respect to the set of shared dimensions) and to compare those cases in order to build analogy-based and distinguishing arguments, as well as counterexamples. On the other hand, CATO-style factors may or may not be present in a given case; if present, they support the position of a given party. Both approaches have their advantages and disadvantages, which cannot be discussed in depth here (but see [33]). PPSS combines these approaches, using both unary factors (Environmental Factors have this characteristic) and dimensions. The differences between HYPO and PPSS dimensions are as follows. Because PPSS assigns one dimension to each category of the parenting plan, each agreement will be indexed by every dimension stored in the system. PPSS dimensions encompass sets of propositional elements (Environmental Factors and options) with a certain valuation on the given dimension. Because each PPSS dimension involves a ten-step scale, it may be defined as a set of ten sets of propositional elements; sets belonging to a given step of the scale have the same valuation. The construction and application of HYPO dimensions are different because their role is to enable analogy-based argumentation. In typical situations, then, only a few dimensions will be present in a given case. HYPO dimensions also involve different scales (binary, ordinal, etc.).

Most importantly, knowledge structures in the present version of PPSS do not enable a fully fledged CBR, which would encompass retrieval of cases, analogizing from one case to another and forming arguments based on similarities and differences. Instead, these structures serve to enhance the contextualised character (Environmental Factors) and systematisation (dimensions) of rule-based reasoning, performed by means of defeasible rules in the assessment of particular clauses of the parenting plan. The use of CBR structures in PPSS differs considerably, then, from their use in existing ODR projects such as UMCourt [32], in which the information that constitutes a case encompasses the following categories:

(i) Problem—encompassing the following information types: background (similar to PPSS Environmental Factors), objectives (aims of the parties), and legal (in particular, applicable norms) and important dates in the case.

(ii) Solutions—list of actions performed by the parties in order to achieve the outcome.

(iii) Outcome—list of items describing the outcome in terms of indemnities to be paid and a value denoting the percentage of successful applications of this case to the dispute resolution process.

UMCourt uses different types of similarity metrics for retrieval of cases, including nearest neighbour and cosine similarity. As an output, the user obtains a list of potentially applicable cases, ordered in terms of their similarity. In particular, if two cases are decided on the basis of the same legal norm, those cases will be considered similar; elements determining the similarity of legal cases may have different weights.

Although this approach to the use of CBR in ODR systems such as UMCourt is valuable, it has limited application to the PPSS project because of the latter's peculiarities. Specifically, the role of PPSS is not to provide the parties with material for arguments in favour of one or other side of the dispute but to enable parents to draft a parenting plan which would optimise realisation of the child's well-being. It follows that results of stored cases (in terms of winning or losing party) would not be useful for the purposes of PPSS. Additionally, proximity of dates will not always indicate cases' similarity, as an old case may well contain an adequate and applicable interpretation of the child's well-being. In respect of preparation of the parenting plan, the governing legal norm will be derived from art. 58 §1 and 1a of the PFCC, as referred to in Section 2, which means that retrieval of cases on the basis of similar legal grounds would be trivial for PPSS.

In order to enhance PPSS with actual CBR tools, enabling retrieval, comparison, and argument from cases, a different approach is needed, in which the actual cases stored in the database should contain as much information as possible about interpretation of the concept of the child's well-being in the circumstances of the case. A first approach to this problem may be found in the work of Araszkiewicz et al. [11], on the basis of which the following questions can be asked:

(1) How should the relevant information for interpretation of the child's well-being in a given case be represented in the knowledge base of the system?

(2) How might this information be applied to other cases, given the limited applicability of both classic factor-based and dimension-based approaches and recent findings concerning the use of CBR in ODR systems?

Recall that the practical idea behind the knowledge structure in the Option Choice Module of PPSS is that parents interested in testing a certain option can obtain a valuation of that option in terms of the child's well-being, based on Environmental Factors they have introduced. This raises the question of how the set DR, as potentially applicable to a given case, should be represented within the system. An exhaustive approach would involve determining a finite set of all propositional elements before deciding on the valuation of each element of the set P(PROP). However, this would be unfounded in terms of descriptive adequacy, as it would be impossible to identify authoritative sources (judgments or scientific works) to justify valuations for all the possible inputs. For instance, if the set PROP encompassed 10 elements (a simple case), it would be necessary to determine the valuation of 1024 (i.e., 2^{10}) rules and then to define the preference relation for them. Such a valuation would be almost completely arbitrary and computationally intractable. A further reason for rejecting this approach is that the aim here is to model the reasoning of the courts and the parties as faithfully as possible in relation to actual instances of argumentation and to provide explanations that are understandable by users. To that end, it is necessary to determine a certain "reasonable" subset of P(PROP). The present research questions are as follows:

(I) How can and should such a reasonable subset be determined?

(II) What should be the syntax of the rule's antecedents, and how is a relation of preference between these rules to be established?

In addressing these questions, the following general problem provides a context for our investigations. Let us assume that a researcher has succeeded in establishing an appropriate knowledge base for a given case (C), encompassing a reasonable set of defeasible rules, properly connected to valuations and related to each other by relation of preference. The present paper is concerned with the incremental building of such a generalised knowledge base, highlighting both the possibilities and the limitations of that development.

4. The Issue of Uniqueness versus Comparability of Cases from the Practical Perspectives of Judge and Mediator

This section discusses the possibility of analogizing from one case to another from the perspective of a lawyer or mediator. It is our opinion that these sources may prove useful in developing more fine-grained methods for CBR inferences in the interpretation of indeterminate concepts. In formulating a directive to treat each case as unique, the commonplace postulate concerning avoidance of routine in the work of a judge, lawyer, or mediator by determination of its factual and legal circumstances (known as diagnosis of the conflict) should be assumed to be methodologically justified. This conforms with the assumption that each human being is an individual, capable of forming unique impressions, desires, and relationships. Against earlier belief in the stable rationality of human motivations, judgments, and decisions, the present state of the art in psychology points to nonschematic patterns in the functioning of the human mind [34].

The influence of intuition, emotional style, heuristics, and social interaction on the thinking and behaviour of human beings means that parties to legal disputes are subject to many cooccurring internal and external determinants. These justify an individual approach to the investigation of any case, taking into account both legal and extralegal (i.e., psychological, communicational, relational, economic, social, and ethical) points of view [35, 36]. At the same time, the practice of law and mediation unambiguously shows that, in taking this approach, it is advisable to (1) compare different cases and disputes in their various aspects; (2) look for any common elements, similarities, or concurrence in the legal and factual features of these cases; (3) conduct comparative investigations concerning the motivations, needs, reasoning, and argumentation of agents in different cases, including those of intervening third persons (judges, arbiters, and mediators); and (4) categorise the different aspects of disputes. Such comparison fosters the optimisation and application of individually and socially appropriate solutions. A multicriteria analysis supporting diagnosis of the dispute enhances interpretation of the concept of the child's well-being in the given situation and any application of judicial and extrajudicial means in realising this value.

The analysed issue will seem obvious in democratic countries governed by law, given the existence of formally binding precedents and the *stare decisis* principle in common law systems, as well as the paradigm of equal treatment of citizens and the right to a fair trial in civil law systems. The comparison of cases is additionally strengthened by the principles of unity of interpretation and unified application of the law within both domestic legal systems and the system of law of the European Union [37]. Such a legal context reinforces work in the fields of ODR and AI and law research relating to amicable resolution of legal problems. It should be emphasised that this conclusion not only pertains to AI-enhanced systems but also is valid in relation to classical mediation. Fairness of outcome, understood as a solution generally accepted in similar situations, is perceived as an important value by parties to disputes.

In the practice of mediation, conducted without the obligatory evidentiary proceedings and qualification of the facts of the case under a valid norm (subsumption), the issue of similarity of cases gains a specific additional dimension. In respecting the voluntary and autonomous character of parties' decisions concerning the conduct of negotiations and the content of any decisions arising (including the agreement itself), the mediators (1) search for and compare common elements between the case in question and past cases (external analysis) and (2) categorise important aspects of both subject matter and agents in the present case (internal analysis). The results of this comparison and categorisation enable mediators to analyse the conflict and to propose solutions that have been tested against past cases and are therefore considered optimal. Categories enabling comparison of cases and the application of adequate, verified solutions include the following:

(1) Conflicts and causes (e.g., conflicts of relations, of values, of factual investigations, of communication, or of interest) [38].

(2) Framing of the dispute (e.g., as a matter of power, of rights, of interests and needs, of aspirations, of identity, or of conflict management) [39].

(3) Conflict-handling modes or ways of dealing with conflict (e.g., competing, collaborating, compromising, avoiding, or accommodating) [40, 41].

(4) Preferred styles of decision-making (e.g., thinking versus feeling) [42].

(5) Personality types of the parties (e.g., on the Myers Briggs scale) [43].

(6) Course and degree of escalation of the dispute.

(7) Life, family, occupation, and social situation of the parties.

(8) Levels and types of needs of the parties [44].

(9) Psychological phase of the conflict (which is particularly important in family disputes involving divorce) [45].

(10) Evidentiary and legal positions of the parties.

Comparative analysis of present and past cases through the prism of the above categories enables the mediator to adequately apply experiences and findings. For instance, appropriate identification and categorisation of the causes of conflict guide the choice of an optimal solution and the manner of the mediator's intervention [37]. The ventilation of emotions, method of negotiation, reality testing, and argumentation applicable to a given category can also be guided by approaches that have previously proved useful in achieving mutual concessions and settlements. In practice, it is also helpful to refer to agreements executed in similar cases, especially where these have been empirically verified and accepted by the courts. Analysis of similarities between cases enables the mediator to use previous positive and negative experiences to predict the likely behavior of the parties and the effectiveness of any chosen means of intervention. Additionally, professional development should emphasise the common practice of anonymization of information exchanged between negotiators, mediators, and lawyers concerning precedents or untypical cases, as well as the need to avoid error and to replicate tested and optimal solutions.

To conclude, while taking into account the individual and unrepeatable character of any human being and their situation, not every case need be considered essentially unique. Despite the diversity of human personalities, motivations, needs, and modes of thinking and argumentation and of the legal and factual features of cases, efficient comparison and categorisation are in practice possible and justified. In continental legal culture, such comparisons may at least provide fruitful examples for analysis of the case at hand [46]. The categories of comparison listed above can fruitfully be applied in developing the CBR module of PPSS.

5. Heuristics Used to Extract Preferences among Rules from Background Knowledge: General Remarks and Discussion of the Literature

Having discussed the methods employed by lawyers and mediators to compare cases and to categorise their important elements, we may now consider how these insights can fruitfully be employed in developing the PPSS knowledge base. In the existing version of PPSS [11], both propositional elements (options and environmental factors) and, in particular, defeasible rules (DR) and preferences between them are predefined within the system. The following defines a context for development of the automated generation of orderings of rules within the constraints of resemblance to actual legal argumentation (i.e., the generated rules should not be overly complex) and computational features of the system.

The intention here is to model the reasoning of a judge who must decide which case features should be counted as more decisive, leading to an assessment of the case with respect to the criterion of the well-being of the child. Such determinations inform continuous updating of the meaning and scope of the (indeterminate) concept of the child's well-being, although in civil law countries the impact of judicial decisions on future cases is much weaker than in common law jurisdictions, where past cases have the status of binding precedent. In the absence of such authoritative sources, both parties to the drafting of parenting plans and judges assessing those plans on the criterion of well-being of the child must use different heuristics to assess the relative importance of features of the analyzed cases. As different people may use different heuristics in addressing a given cognitive problem, it would be implausible to advance a set of universally used heuristics. The selection presented below is therefore to some extent arbitrary and clearly nonexhaustive. It was developed on the basis of the authors' experience of both theory and practice of legal cases involving family disputes within the framework of Polish law.

Most obviously, a heuristic may be defined as a nonalgorithmic problem-solving strategy (*locus classicus* [46]). In framing the PPSS knowledge base, we are less interested in the process of decision-making under uncertainty than in the process of grasping the important features of the analysed case and assessing their relative importance with regard to the criterion of well-being of the child. Given the defeasible character of reasoning based on heuristics, it is always possible that this may lead to a fallacious decision in concrete cases, accounting for the possible disagreement of PPSS users with suggestions and valuations provided by the system [47]. Our aim is to develop a knowledge base that will decrease the likelihood of such disagreements.

Some of the main heuristics used in determining preference relations between defeasible rules to interpret aspects of the concept of the child's well-being may be classified as follows.

(1) Subjective Decision of the Agent Deciding on the Relation of Preference. In such situations, establishing a relation of preference between rules is based on arbitrary or intuitive choices. In some instances, in the absence of any accessible source from which derive the preference relation and the grounds for establishing it, an arbitrary choice may be the only available option.

(2) The Law (in the Broad Sense of the Term), Encompassing Statutory Sources, Case Law, and Doctrinal Elaborations. In particular, judicial decisions are a rich source in establishing preference relations between rules for the interpretation of indeterminate legal concepts. However, in civil legal systems, the rules expressed in judicial decisions cannot generally be considered binding and cannot therefore strictly constrain the decision-making processes of interested parties or of the court. In these circumstances, relative preference relations between rules encompassing features of cases expressed in judicial decisions in civil law countries can be seen as no more than weak constraints on reasoning in new cases. Even striking similarities between new and old cases do not warrant application of the previously expressed preference

relation, although they may in practice provide good reason for its application.

(3) Commonsense Reasoning. This provides an abundance of heuristics, applicable to a potentially infinite number of cases. In the first place, commonsense reasoning may play a negative role by eliminating absurd or unreasonable preference relations between rules and subsequently a positive role in seeking an ordering of rules that appears "most reasonable." Clearly, these heuristics may lead to defeasible results.

(4) Appeals to Morality and/or Teleological Reasoning. This type of heuristic enables an agent to argue that rule r_1 is preferred over rule r_2, for example, because the former realises a more important value or because it realises some given value to a greater extent. Background knowledge related to values is a source of heuristics under the concept of balancing; generally speaking, a rule may be assessed as the preferred one where its application leads to the most favourable balancing of relevant values. The idea of balancing values naturally assumes that the realisation of one value may to some extent limit the possibility of fully realising other values. As the child's well-being should itself be treated as a value, we refer here to a set of lower-level values or goals that may contribute to the realisation of this paramount value (e.g., good communication between parents and children, good financial situation, or children's safety). In fact, these lower-level values are represented in particular dimensions of PPSS, although in a distributed manner.

There is an abundant literature (in AI, AI and law, and legal theory) concerning the establishment of preferences between arguments based on rules and comparison of sets of reasons in rule-based reasoning. For obvious reasons, it is not possible to discuss all these research streams in depth here. Instead, we will focus on selected relevant works to demonstrate how our approach contributes to the state of the art. It is important to emphasise that the problem of establishing preference relations between conflicting legal rules is beyond the scope of our investigations, which focus on relative preferences in the assessment of a given factual situation from the point of view of a single indeterminate legal criterion, in this case, the concept of well-being of the child.

In terms of general research on AI and argumentation, there exists a vast literature on preference-based argumentation. This work focuses on formal properties of developed theories, often within the frame of abstract argumentation. This idea has been introduced to a wider audience by Dung [48] and in theories concerning structured or instantiated argumentation. For instance, Modgil and Prakken [5] have recently presented a fully fledged account of argumentation with preferences, rooted in Dung's theory but capable of expressing a wide range of instantiations by means of the ASPIC^+ formalism. Although this line of research is of great importance, its relevance for PPSS is limited at this stage of the system's development, as PPSS does not allow users to argue about relative preferences for rules by means of a computational model of argumentation. Rather, the aim of the PPSS inference engine is to infer the correct valuation of the given case and to present it to users of the system, with suggestions for changes to chosen options.

Another important precedent informing PPSS is the model of teleological reasoning incorporating cases and values developed by Bench-Capon and Sartor [19], which was designed to build theories of cases from background knowledge (encompassing, *inter alia*, cases and factors) and to evaluate those theories against a criterion of coherence. Although PPSS does not employ the notion of theory, an important aspect of that model for the PPSS knowledge base is the set of heuristics (referred to as "theory constructors") used to infer certain theoretical elements from background knowledge. In particular, Bench-Capon and Sartor discuss procedures for the extraction of value preferences from cases, as well as rule preferences based on value preferences. In the present version of PPSS, there are no rules that would enable the system to abduct value preferences from the ordering of rules in cases. This is problematic because the formalistic and magisterial style of the Polish courts often makes it difficult to reconstruct the details of teleological reasoning. However, the existence of such considerations in certain judgments stored in the PPSS database opens the possibility of extending the inference engine in this way. In summary, it should be stressed that the heuristic character of establishing preference relations between rules in PPSS should be seen as (possibly justified) advice to users rather than as an authoritative solution.

6. Selected Technical Issues

It seems important to point out two disadvantages of the model presented in previous versions [11] of PPSS: the lack of discussion of possible utilisation of negation in the conditional part of defeasible rules and the necessity for manual extraction of defeasible rules' preferences. This section will address these problems, suggesting a first step towards automation of the process.

The problem of negation is of particular importance because, at the first sight, it is difficult to imagine a legal decision support system with no possibility of negation, given that negation appears so frequently in both legal and commonsense rules. Generally speaking, two kinds of negation may be distinguished in formal logic as follows:

(i) Classical (strong) negation (denoted by $\neg$) in the conditional part of the rule is fulfilled if it is known that a given proposition is not true.

(ii) Negation as failure (denoted by $\sim$) is fulfilled if every possible proof of a given proposition fails.

If we allow for utilisation of both kinds of negation in the conditional part of the rule, we may use a construction like $\sim \neg P$, usually interpreted as "it is not known that not P."

In [3], Sergot et al. describe a legal expert system that models the British Nationality Act, in which they use only negation as failure. The problem of double negations (including one classical negation) was solved by changing a negative literal ("X was not born in the UK") into a positive one ("X was born outside the UK"). From another point of view, many other logical models of legal reasoning [21] allow for utilisation of both kinds of negation. Other expert systems (such as that used for evaluation of the quality of protection of IT systems [49]) allow for utilisation of negation as failure in the conditional part of the rule only and for classical negation in the consequence part of the rule.

It is important to understand which kind of negation (if any) is most suited for modelling defeasible rules in PPSS. Utilisation of negation as failure seems more flexible, and Sergot et al. [3] use it in their system. However, in the specific legal context of rules for evaluating the well-being of a child, where the chosen option has a positive character, the existence of environmental factors must be justified. Even the negated factor (e.g., "no cooperation between parents") should be explicitly stated and strictly justified on the basis of evidence, making negation as failure unnecessary in this specific kind of legal rule. Moreover, as in [3], classical negation may be replaced by positive propositions or by propositions such as "no cooperation," which may be treated in the same way as ordinary positive propositions. To bear on an assessment of options chosen by the negotiating parents, a lack of certain circumstances should be asserted as a "positive fact." Such a conception of defeasible rules has interesting consequences, which will be discussed later.

It is trivial to say that a legal expert system incorporating an Explanation Module should accurately reflect the reasoning of a human lawyer. Defeasible rules in PPSS should also mirror rules by which a human actor evaluates the influence on one of the dimensions representing the well-being of the child of a chosen option and the context of a case as described by a set of factors. The same option in a different context may vary in its influence on a given dimension, making it important to choose the rule referring to the context at hand. This is important because the occurrence or nonoccurrence of one particular factor can critically alter evaluation of a given dimension.

Example 1. Let us consider two defeasible rules from the example presented in [11] as follows:

$$r_1 \colon \alpha \wedge \delta \wedge \gamma \Rightarrow 3.$$
$$r_3 \colon \alpha \wedge \delta \wedge \gamma \wedge \mathrm{ef2} \Rightarrow 0.$$
$$r_1, r_3 \in \mathrm{DR}(Di).$$

When α, δ, and γ are options, ef2 is environmental factor.

In our case, if we assume that factor ef2 exists and we choose all three options ($\alpha \wedge \delta \wedge \gamma$), the conditions of both rules will be satisfied, leading to a conflict. How can such a conflict be resolved? There are two possible ways; the first of these is to add the possibility of negation (negation as failure) of the condition of the rule, with additional conditions to rule r_1, excluding the existence of ef2, as in Example 2.

Example 2. Consider

$$r_1 \colon \alpha \wedge \delta \wedge \gamma \wedge \sim \mathrm{ef2} \Rightarrow 3.$$
$$r_3 \colon \alpha \wedge \delta \wedge \gamma \wedge \mathrm{ef2} \Rightarrow 0.$$
$$r_1, r_3 \in \mathrm{DR}(Di).$$

Such a solution has one important disadvantage; rule r_1 (as well as r_3) should also contain clauses excluding other factors that can alter evaluation of a chosen option. In real-life situations, there may be a number of such clauses, making such a rule counterintuitive and difficult to understand.

The second way to overcome the problem of conflicting rules is to assume that, in cases of conflict between two (or more) rules, one of them is preferred to the others, as in Example 3.

Example 3. Consider

$$r_1 \colon \alpha \wedge \delta \wedge \gamma \Rightarrow 3.$$
$$r_3 \colon \alpha \wedge \delta \wedge \gamma \wedge \mathrm{ef2} \Rightarrow 0.$$
$$r_3 > r_1 \in \mathrm{ORD}_{\mathrm{C}}.$$

There is a long history of ordering rules in formal models of legal reasoning. However, our case is specific. First, we must detect which rules are in conflict. Unlike advanced models of reasoning and argumentation, only one defeasible rule can be used in our model to evaluate the level of promotion of a given dimension. It follows that if a given case satisfies the conditions of more than one rule, then all these rules are in conflict. Second, we have to discover and justify the sources of order between conflicting rules. There may be many such roots, from legal principles like *lex specialis*, *lex superior*, or *lex posterior*; they may also come from preferences between values. These issues are extensively discussed in the literature, as, for instance, those in Sartor [50]. The case described in the above example is interesting because every case satisfying the conditions of rule r_3 also satisfies the conditions of rule r_1. On that basis, we may say that the conditional part of rule r_1 subsumes the conditional part of rule r_3. How are we to deal with such cases? The most intuitive way is to observe that rule r_3 should be treated as an exception to the more general rule r_1, and so, on the basis of the principle of *lex specialis derogat legi generali* (in which the specific act (provision) derogates from (prevails over) the general regulation [50]), we may assume that r_3 is preferred to r_1. Here, we are using this collision rule analogically, as the rules employed in PPSS will rarely have a strictly legal character; rather, they are "judicially authorised" commonsense rules, used by courts in issuing opinions. Of course, conflict may arise not only between rules with subsuming conditional parts; in such situations, preference relations between rules should be built on the basis of the other justifications. It is our opinion that conflict resolution by the ordering of rules seems more intuitive and better reflects human reasoning; for that reason, a generalisation and formalisation of this method are offered below.

On the basis of the above and [11], the following new elements can be added.

Definition 4 (conflicting rules). If one has two rules r_x and r_y ($r_x\ r_y \in \mathrm{DR}(Di)$) assigned to a Dimension i, and there exists a case that satisfies conditional parts of both of them, and the consequents of r_x and r_y are not identical, then rules r_x and r_y are in conflict.

On the basis of the above definition of conflict, we can create a conflict resolution method based on the analogical application of the collision rule of *lex specialis* as widely applied in the context of conflict between statutory rules. By applying this method, we can automatically add a new order to a set ORD_C that allows us to defeat conflicting and less preferred rules.

Definition 5 (lex specialis). If one has two conflicting rules r_x and r_y, and if

(i) Ω is a conditional part of the rule r_x, which is a conjunction of options chosen by the parents (Ω_{X1}) and circumstances of the case (conjunction of environmental factors Ω_{X2}), and

(ii) the rule r_y has a conditional part of the form $\Omega \wedge \Omega_y$, where Ω_y is a finite conjunctive formula encompassing elements taken from the set of EFs,

then rule r_y is preferred to rule r_x, and the relation $(r_y > r_x)$ should be added to ORD_C.

We may add that if $r_y > r_x$, then the conclusion of r_y rather than the conclusion of r_x is counted as true in a given factual situation.

The above definitions require some additional comments. As the conditional part of defeasible rules is a conjunctive formula of positive propositions, creating a new rule by adding a new condition to an existing rule will narrow its scope. Such a new rule can be treated as a special exception to the old one; on the basis of the principle of *lex specialis*, then, it should take higher priority in cases of conflict than the old one. This is illustrated in Example 6.

Example 6. Let us assume the following rules from Example 1:

r_1: $\alpha \wedge \delta \wedge \gamma \Rightarrow 3$.

r_3: $\alpha \wedge \delta \wedge \gamma \wedge \mathrm{ef2} \Rightarrow 0$.

$r_1, r_3 \in \mathrm{DR}(Di)$.

Set ORD_C is empty: $\mathrm{ORD}_C = \emptyset$.

Let us assume that, in our case, environmental factor ef2 occurs and that parties choose options: α, δ, and γ; hence, rules r_1 and r_3 are in conflict.

If we substitute Ω for the formula $(\alpha \wedge \delta \wedge \gamma)$, then both our rules will take the following forms:

r_1: $\Omega \Rightarrow 3$.

r_3: $\Omega \wedge \mathrm{ef2} \Rightarrow 0$.

As the conditions of application of *lex specialis* are satisfied, we add order $r_3 > r_2$ to set ORD_C, thus resolving the conflict.

The model of *lex specialis* presented above enables avoidance of a special kind of conflict that may appear in the set of defeasible rules. Of course, it does not allow resolution of all possible conflicts that might appear in the DR set. If such a conflict appears, one of the other heuristics should be used to resolve it.

7. Conclusions

Despite impressive progress in the field of development of legal expert systems, it remains far from clear how such systems should be developed to make them useful in practice, in dealing with nontrivial cases. The present paper contributes to this line of research in a very specific context defined by the conjunction of the following elements: (1) continental legal culture, where there is no precedential constraint; (2) nonadversary proceedings, where parties are motivated to cooperate rather than to argue against each other but may still have diverging interests; and (3) highly indeterminate, as in the open-textured and evaluative concept of the well-being of the child.

Our main findings are as follows. It would be computationally intractable and descriptively inadequate to seek to apply exhaustive algorithms to interpret the well-being of the child by means of classical hybrid rule-based and case-based knowledge representation structures. To provide users with an explanation of outputs that simulates the reasoning of an actual lawyer or mediator, certain heuristics should be applied to provide defeasible rules interpreting this concept in concrete cases, as well as preferences between these rules. It is unnecessary to utilise any form of negation in the syntactical structure of these rules; the specificity of description of the case in the antecedent of the given rule provides a very convenient heuristic for establishing priorities between rules. As a matter of course, this proposal is subject to debate, not least because the specificity of rules utilised here falls within the domain of commonsense rather than of strictly legal rules. In particular, effective utilisation of the specificity principle requires the knowledge of engineering to structure the system of environmental factors to establish a hierarchy of more general concepts and exceptions thereof. The limitations of this approach will be the subject of future investigations relating to the PPSS project.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Distilling Big Data: Refining Quality Information in the Era of Yottabytes

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Big Data is the buzzword of the modern century. With the invasion of pervasive computing, we live in a data centric environment, where we always leave a track of data related to our day to day activities. Be it a visit to a shopping mall or hospital or surfing Internet, we create voluminous data related to credit card transactions, user details, location information, and so on. These trails of data simply define an individual and form the backbone for user-profiling. With the mobile phones and their easy access to online social networks on the go, sensor data such as geo-taggings and events and sentiments around them contribute to the already overwhelming data containers. With reductions in the cost of storage and computational devices and with increasing proliferation of Cloud, we never felt any constraints in storing or processing such data. Eventually we end up having several exabytes of data and analysing them for their usefulness has introduced new frontiers of research. Effective distillation of these data is the need of the hour to improve the veracity of the Big Data. This research targets the utilization of the Fuzzy Bayesian process model to improve the quality of information in Big Data.

1. Introduction

Big Data systems are the eventual outcomes of today's data centric world. In this 21st century, we cannot imagine passing a single day without the touch of Internet. In fact the World Wide Web, online social networks, and extensive computerization of our everyday activities have put forth new phenomena in managing the data thrown out by these processes. By virtue of its multidimensional nature, comprising volume, velocity, variety, variability, and veracity (5Vs), Big Data poses serious research issues and its complexity is always in the increasing trend. The beauty of Big Data is the fact that it incorporates all types of data, not just pictures, texts, sounds, emails, and so forth, but also the inputs and outputs from sensors of any kind. Also these data can be either unstructured type arising out of social media transactions or even multistructural type which is the outcome of interactions between people and machines. The architecture of Big Data is different from the data warehousing solutions, as this architecture should cater to the 5Vs and should produce meaningful results [1].

According to a report by Forbes, the seed for the term Big Data was first sowed on the Communications of the ACM by Steve Bryson in the year 1999. This paper has highlighted the fact that advances in powerful computing threw out huge volumes of data and understanding from these data is a significant endeavour. Since then, the growth of Big Data occurred in a rapid manner with the increase in computing power and reduction in the cost of storage devices. Earlier, data capacity in the order of gigabytes (GB) looked big, but now terabytes (TBs) have become so common such that even desktop computers sport hard disk drives of 2TB. According to a recent study [2], the digital universe is doubling in its size every two years and the amount of data we generate and copy annually will become 44 trillion gigabytes or 44 zettabytes by 2020. More than 2 billion people and several million enterprises are doing their works online, thereby generating mass volumes of data. A single celeb-selfie tweet by Ellen DeGeneres who hosted the Oscars of 2014 was viewed 26 million times across the world within a short span of 12 hours, which shows the power of a single tweet to generate enormous data. In 2013, only 22% of the entire information processed in the digital universe was found to be useful if it has been properly tagged and a meagre 5% contained quality data. By 2020, the useful percentage of data may grow up to 35%, due to the contribution of data from embedded devices.

Parallel developments in the arena of Internet of Things (IoT) will accelerate the growth of Big Data with the sensors in mobile phones and other handheld devices pumping their own contributions [3]. New data sources leading to novel methodologies for data distilling and applying the outcomes to business processes so as to reap profits have become the cliché of successful businesses across the world. In short, smart work has outpaced the concept of hard work and proper data distillation techniques are needed to extract quality valuable data from the data dumps.

The people of today's Internet age have become more and more conscious about the markets. It has become increasingly tough to sell products to them and conventional marketing methodologies have become obsolete. In the financial sector, decision making has been revolutionized. Predictive analysis has entered into new dimensions about the functioning of stock markets and can provide a detailed insight about various investment portfolios. On the healthcare front, Big Data can help you arrive at tailor made solutions based on your past medical history. The new path breaking strategies in human genome mapping with Big Data tools, wherein genes are being mapped to the diseases as per the earlier medical records, can help doctors pinpoint the actual medicine to be administered.

2. Social Sensing

Social sensing is the new technology of human centric sensing, wherein the sensors are attached to the humans in a wearable form or use the mobile devices like cellphones which carry the sensors like GPS, camera, and so forth. As these mobile devices are capable of automatically connecting to the Internet, the data sensed by them can be accessed in no time across the connected applications and devices. Numerous applications like Cabsense, Bikenet, and Cenwits use the social sensing for their operations. In the field of healthcare, this concept has created wonders in continuously monitoring patient's vital data, emergency response, prediction about diseases, lifestyle effect on health, and so forth. Social sensing can be either voluntary/intentional or involuntary/unintentional. The former involves the participation from the user to identify the symptoms and causes whereas the latter does not have any user interaction and can happen without the knowledge of the user. Examples of user assisted sensing include marking the routes with more traffic and spotting the litter. The unassisted social sensing utilizes the built-in GPS of the hand held smart devices to automatically geo-tag the user and can use accelerometer to detect motion, and so forth. Reporting of natural calamities and civil unrest, on Twitter, Facebook, and YouTube, provides a global forum for sharing data on real time basis. Several research attempts are being made to understand the functioning of these online social sensing applications in propagation of information, characteristics, and tipping points.

3. Literature Review

With rapid decrease in the storage costs and dramatic increase in the computational capabilities, the size of the data is no longer a heinous factor and the quality of the data under study has become the primary concern. In one study by IBM, it was found that US $3.1 trillion was lost every day due to poor data quality and the survey has shown that 27% of the respondents were not sure about their own data. Since majority of the data come from anonymous unverified and untagged sources, the quality of the data needs to be flagged before it is used in any task [4]. Until recently, the Big Data has been characterized only by 3Vs, namely, volume, velocity, and variety, and the content looks more like a soup with the content providers scooping out and dumping them into information systems [5]. But with the introduction of data quality as a key factor, the fourth dimension of Big Data, namely, veracity, came into the picture which focusses on Information Quality (IQ) [6]. However big the quantity of data is, it will not be of any use if it does not have any meaningful extractable information and this research aims at providing a solution to the problem of data quality. Uncertainty in the data leads to unreliable information. This issue of uncertainty may be broadly classified into three heads, namely, process uncertainty, data uncertainty, and model uncertainty. The examples for process uncertainty are uncertain travel times in a GPS based tracking environment, yield of semiconductors, and so forth, and the data uncertainty involves inconsistency, ambiguity, incompleteness, conflicting data, and so forth. Model uncertainty comes into picture in the event of prediction and forecasting services where all models are approximations only. The data quality can generally be grouped under several categories like accuracy, believability, reputation, objectivity, factuality, consistency, freedom from bias, correctness, and unambiguousness. But with the introduction of uncertainty, all these factors have to be revisited to evolve a perfect working solution [7–11]. Figure 1 shows the 4Vs of Big Data as proposed by IBM [11].

Meeker and Hong [12] have discussed the opportunities and challenges in the Big Data related to the warranty and insurance claims in a typical industrial environment. With the technological advancements, leading to the implantation of sensors within the products, we can easily measure various parameters like use rate, system load, and environmental factors from these embedded sensors. The concepts represented in this research refer to the Internet of Things and the data are referred to as the SOE (System Operation/Environmental)

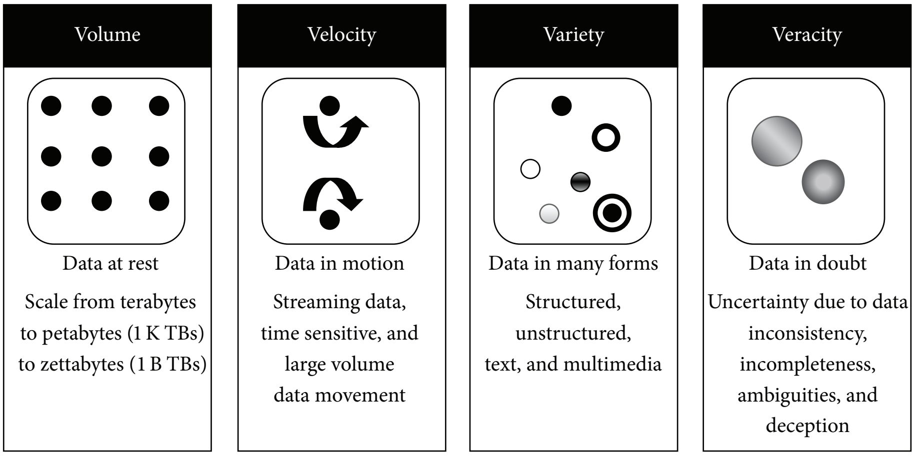

Figure 1: 4Vs of Big Data.

Data and they can be well used to analyse the reliability issues. Locomotive engines, aircraft engines, power distribution transformers, CT scan devices, wind turbines, and solar energy power invertors are some examples where such sensor data are available to predict the reliability of the system.

Uddin et al. [13] extensively analysed the social sensing and have developed algorithms for improving the source selection in social networks like Twitter, Flicker, and so forth. These social networks provide unprecedented opportunities to develop sensor applications where humans either act as sensors or play as sensor operators by posting the observations or measurements in an online medium. As the observations posted by one user are available to other users, any wrong or faulty information by one user may pass on to others since there is no mechanism to verify its correctness. Baseless rumours that will mislead the facts may also propagate in these online networks thereby creating bias. Uddin et al. have found that social sensing brings in new type of inaccuracy called unknown dependence between the sources which affects the creditability of data. They have adopted the concept of diversifying the sources to extract quality information. However, their technique used the follow relationships in the Twitter as a method of measurement and does not focus on the geographic locations and community they belong to in the process of assessment.

Maximum likelihood estimation (MLE) method [14] was adopted to find the accuracy of the participants and this technique utilizes the Cramer-Rao bound for estimation purposes. This method provides an insight into participants reliability without knowing their reliability a priori. Fisher information was initially computed by using the asymptotic normality of MLE. Though satisfactory results were obtained, a tighter Cramer-Rao bound can be derived to measure the truthfulness of the variable.

Aggarwal and Abdelzaher [15] discussed in detail the social sensing applications in the web like Google latitude, Citysense, Macrosense, Wikitude, Green GPS, and so forth. With the development of miniaturized sensor technology, sensors can even be embedded in the cloth fabric and the user can wear the attire without any obstruction or protrusion. 3G/4G mobile wireless networks have virtually bridged the bandwidth performance between wired and wireless networks. Online real time stream processing systems have also been developed to fetch and analyse the sensor data on the fly. But these real time systems bring in several issues like data compression, challenges in handling multiple data streams, data collection in mobile devices, and so forth. Also privacy and trust factors always collide with each other as one demands data fidelity and the other denies it. With the inroads created by Big Data, certain new dimension has also been put forth by Mishra and Sharma [16] by introducing the concept of value and an in-depth study has been made in the significant developments in the area of national development, industrial upgrades, interdisciplinary research, and better perception of the present scenarios of any industry. An interesting work carried out by Najafabadi et al. [17] has focussed on the importance of applying deep learning methods and evolving strategies to yield better results in the analysis of Big Data. They have introduced the concept of feeding a part of the available data corpus into deep learning algorithms and utilizing the remaining input data corpus for pattern recognition to extract data abstractions and representations. Thus the variety characteristic of Big Data, which focuses on the varied input data types for training the data representations and the target data source for generalizing the representations, becomes a problem of domain adaptation in deep learning. Their research has also explored the selection of criteria to provide useful semantic meaning.

The veracity of a Big Data environment depends on various factors, which include trustworthiness and expertise. These two factors are responsible for providing credible judgments about the quality of data. Objectivity, truthfulness, and credibility have been designated as the three main theoretical dimensions of veracity [18]. Various Big Data problems can be characterized by these dimensions based on quality.

4. System Design

One of the critical questions in the research of social sensing is about the reliability of the data collected by the humans. The process of contributing information is open and we never had any filtering mechanism to identify the reliability of the humans who act as sensors. Trust analysis of social sensing data is still an underdeveloped area that needs new techniques to improve reliability and enhance quality of information. This paper aims at creating a suitable framework to measure the reliability of data sensing sources and also to study the exactness of their responses. This approach is based on the Fuzzy Bayesian Interpretation model [19–23] where the data is processed on the server side using software only and no specialized hardware is required. Though this paper has addressed the explosion of data and has covered in depth the size of zettabytes and yottabytes, this research has utilized the simulation of an information network comprising "n" number of sources and assertions. A network model based approach can be visualised for solving the reliability issues, with the nodes representing the unreliable information and the links representing the abstract relations. Let there be sources $S_1, S_2, S_3, \ldots, S_s$, who collectively affirm information $C_1, C_2, C_3, \ldots, C_c$. If these sources and assertions are made to represent the nodes, then the links between the corresponding source nodes and the assertion nodes are represented by C_{ij}. Then the creditability of the sources is given by Cred (S_i) and that of the assertion given by Cred (C_j).

5. Methodology

5.1. Bayes Interpretation. We propose to use the Bayesian interpretation to rank the various sources providing information based on the creditability values. The statement of Bayes' theorem is

$$p(h \mid e) \propto p(e \mid h)\, p(h), \tag{1}$$

where $p(h \mid e)$ and $p(e \mid h)$ are conditional probabilities. For example, if $p(e \mid h)$ is the probability of e based on the condition of h, according to Bayes rule, whenever an evidence of e is received, $p(h)$ has to be updated by $p(h \mid e)$. We have to multiply the prior probability $p(h)$ by the prior likelihood $p(e \mid h)$ followed by the normalization such that all probabilities sum to 1. The resulting posterior probability $p(h \mid e)$ is the revised probability assignment for h. Therefore, the new probability of h is proportional to its original probability, multiplied by the likelihood of evidence e given h [24].

A Bayesian model can well be explained by using the following template and it forecasts an outcome through four factors, namely, prior probabilities, prior likelihoods, sensory input, and the utility function. This shows that the proposed model is deterministic and it has been depicted in Figure 2. However certain sensory malfunctions, internal noise leading to corruption can be the basis for exceptions. Certain models also replace the expected utility maximisation with probability matching leading to a nondeterministic process.

A Bayesian interpretation proposed by Dong Wang et al. [25] involves the evaluation using multiple sources

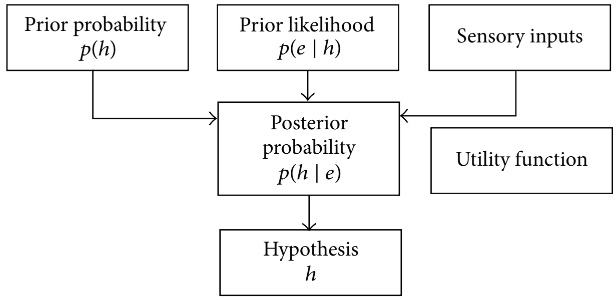

Figure 2: Typical Bayesian model.

$S_1, S_2, \ldots, S_j$ with assertions C_j. Then according to the Bayes theorem,

$$\begin{aligned} P\left(C_j^t \mid S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right) \\ = \frac{P\left(S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j \mid C_j^t\right)}{P\left(S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right)} P\left(C_j^t\right). \end{aligned} \tag{2}$$

Here an implicit assumption is made that the probability of a source making any assertion in low and no change in posterior probability can be made from the nonavailability of claim. This shows that only existing claims are considered. Assuming, for any given assertion, the probability that any two sources claiming the same status are independent, then the equation can be rewritten as follows:

$$\begin{aligned} P\left(C_j^t \mid S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right) \\ = \frac{P\left(S_{i1}C_j \mid C_j^t\right), \ldots, P\left(S_{ik}C_j \mid C_j^t\right)}{P\left(S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right)} P\left(C_j^t\right). \end{aligned} \tag{3}$$

If the change in posterior probability is found to be small and this case arises when evidence is collected from several unreliable sources,

$$\frac{P\left(S_{ik}C_j \mid C_j^t\right)}{P\left(S_{ik}C_j\right)} = 1 + \delta_{ikj}^t. \tag{4}$$

Similarly,

$$\frac{P\left(S_{ik}C_j \mid C_j^f\right)}{P\left(S_{ik}C_j\right)} = 1 + \delta_{ikj}^f, \tag{5}$$

where

$$\begin{aligned} \left|1 + \delta_{ikj}^t\right| \ll 1, \\ \left|1 + \delta_{ikj}^f\right| \ll 1. \end{aligned} \tag{6}$$

Hence the equation can be rewritten as

$$P\left(S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right) \approx \prod_{k=1}^{Kj} P\left(S_{ik}C_j\right). \tag{7}$$

Substituting the same in (2) we get

$$P\left(C_j^t \mid S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right) = \frac{P\left(S_{i1}C_j \mid C_j^t\right), \ldots, P\left(S_{ik}C_j \mid C_j^t\right)}{P\left(S_{i1}C_j\right), \ldots, P\left(S_{ik}C_j\right)} P\left(C_j^t\right), \tag{8}$$

and rewriting it gives the following:

$$P\left(C_j^t \mid S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right) = \frac{P\left(S_{i1}C_j \mid C_j^t\right)}{P\left(S_{i1}C_j\right)} \times \frac{P\left(S_{ik}C_j \mid C_j^t\right)}{P\left(S_{ik}C_j\right)} \times P\left(C_j^t\right). \tag{9}$$

Substituting from (7),

$$P\left(C_j^t \mid S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right) = P\left(C_j^t\right) \prod_{k=1}^{Kj} \left(1 + \delta_{ikj}^t\right) = P\left(C_j^t\right) \left(1 + \sum_{k=1}^{Kj} \delta_{ikj}^t\right). \tag{10}$$

As higher orders of δ_{ikj}^t can be neglected,

$$\frac{P\left(C_j^t \mid S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right) - P\left(C_j^t\right)}{P\left(C_j^t\right)} = \sum_{k=1}^{Kj} \delta_{ikj}^t,$$
$$\delta_{ikj}^t = \frac{P\left(S_{ik}C_j \mid C_j^t\right) - P\left(S_{ik}C_j\right)}{P\left(S_{ik}C_j\right)}. \tag{11}$$

5.2. Creditability of Sources. Let S_i be the source of information making claims Claims_i and j_k denotes the kth claim of Claims_i and $|\text{Claims}_i| = L_i$. By the Bayes theorem,

$$P\left(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right) = \frac{P\left(S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL} \mid S_i^t\right)}{P\left(S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right)} P\left(S_i^t\right). \tag{12}$$

As earlier assuming the conditional independence,

$$P\left(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right) = \frac{P\left(S_iC_{j1} \mid S_i^t\right), \ldots, P\left(S_iC_{jL} \mid S_i^t\right)}{P\left(S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right)} P\left(S_i^t\right). \tag{13}$$

Since the change in posterior probability arising out of any single claim is negligible,

$$\frac{P\left(S_iC_{jk} \mid S_i^t\right)}{P\left(S_iC_{jk}\right)} = 1 + \eta_{ijk}^t, \tag{14}$$

where $|\eta_{ijk}^t| \ll 1$.

Hence,

$$\frac{P\left(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right) - P\left(S_i^t\right)}{P\left(S_i^t\right)} = \sum_{k=1}^{Li} \eta_{ijk}^t,$$
$$\eta_{ijk}^t = \frac{P\left(S_iC_{jk} \mid S_i^t\right) - P\left(S_iC_{jk}\right)}{P\left(S_iC_{jk}\right)}. \tag{15}$$

5.3. Iterative Algorithm. In the preceding sections, posterior probability was derived based on the assumption that either an assertion is true or the source is truthful and they were derived from δ_{ikj}^t and η_{ijk}^t:

$$P\left(S_iC_j \mid C_j^t\right) = \frac{P\left(S_iC_j, C_j^t\right)}{P\left(C_j^t\right)}, \tag{16}$$

where

$$P\left(S_iC_j \mid C_j^t\right) = P\left(S_i \text{ speaks}\right) \cdot P\left(S_i \text{ Claims } C_j \mid S_i \text{ speaks}\right) \cdot P\left(C_j^t S_i \text{ speaks}, S_i \text{ Claims } C_j\right). \tag{17}$$

Since the ground truth is unknown, the probability is estimated by considering the best information we have which is $P(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL})$. Thus,

$$P\left(S_iC_j, C_j^t\right) = \frac{P\left(S_i \text{ speaks}\right) P\left(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right)}{C}. \tag{18}$$

Substituting this into the above equations we get

$$P\left(S_iC_j, C_j^t\right) = \frac{P\left(S_i \text{ speaks}\right) P\left(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right)}{C\text{true}}. \tag{19}$$

Similarly,

$$P\left(S_iC_j\right) = \frac{P\left(S_i \text{ speaks}\right)}{C}. \tag{20}$$

Therefore by rearranging we get

$$\delta_{ikj}^t = \frac{P\left(S_{ik}C_j \mid C_j^t\right) - P\left(S_{ik}C_j\right)}{P\left(S_{ik}C_j\right)},$$
$$\delta_{ikj}^t = \frac{P\left(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right)}{C\text{true}/c} - 1. \tag{21}$$

If we consider the fractions of all true assertions to the true assertions total as prior probability, for a source to be truthful, $P(S_i^t)$, then the above equation can be rewritten as

$$\delta_{ikj}^t = \frac{P\left(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right)}{P\left(S_i^t\right)} - 1. \tag{22}$$

Substituting for δ_{ikj}^{t} we get

$$\frac{P\left(C_j^t \mid S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right) - P\left(C_j^t\right)}{P\left(C_j^t\right)} = \sum_{i=1}^{Kj} \frac{P\left(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right) - P\left(S_i^t\right)}{P\left(S_i^t\right)}. \quad (23)$$

Similarly it can be proved that

$$\eta_{ijk}^{t} = \frac{P\left(S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right)}{P\left(C_j^t\right)} - 1,$$

$$\frac{P\left(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right) - P\left(S_i^t\right)}{P\left(S_i^t\right)} = \sum_{j=1}^{Li} \frac{P\left(C_j^t \mid S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right) - P\left(C_j^t\right)}{P\left(C_j^t\right)}. \quad (24)$$

Comparing the above equations we derive the creditability rank scores $\text{Rank}\,(S_i)$ and creditability rank assertions $\text{Rank}\,(C_j)$ using the iterative fact finding method:

$$\text{Rank}\,C_j = \frac{P\left(C_j^t \mid S_{i1}C_j, S_{i2}C_j, \ldots, S_{ik}C_j\right) - P\left(C_j^t\right)}{P\left(C_j^t\right)} = \sum_{k \in \text{Sources}_j} \text{Rank}\,S_k,$$

$$\text{Rank}\,S_i = \frac{P\left(S_i^t \mid S_iC_{j1}, S_iC_{j2}, \ldots, S_iC_{jL}\right) - P\left(S_i^t\right)}{P\left(S_i^t\right)} = \sum_{k \in \text{Claims}_i} \text{Rank}\,C_k. \quad (25)$$

When the creditability ranks are found such that they satisfy these equations, along with the assumption that with the prior probability assertion is true being initialized to $p(t/a) = \text{Ctrue}/c$, it gives us the

$$P\left(C_j^t \mid \text{network}\right) = p_a^t\left(\text{Rank}\left(C_j\right) + 1\right). \quad (26)$$

Similarly if p_s^t is the prior probability of a chosen source telling truth then

$$P\left(S_i^t \mid \text{network}\right) = p_s^t\left(\text{Rank}\left(S_i\right) + 1\right). \quad (27)$$

Hence the abovementioned Bayesian analysis provides the platform for finding the probability for each individual source S_i and assertions C_j to be true.

5.4. Fuzzy Bayesian Inference. A fuzzy posterior approximator has been applied to yield

$$F(\theta \mid x) = \sum_{j=1}^{m} p_j(\theta)\, C_j^i(x \mid \theta), \quad (28)$$

where

$$C_j^i(x \mid \theta) = \frac{C_h G(x \mid \theta)}{\sum_{i=1}^{m} \int_d G(x \mid u)\, p_i(u)\, C_h i\, du}. \quad (29)$$

Adding fuzzy rules and weights we get

$$F(\theta \mid x) = \frac{\sum_{i=1}^{m} w_F a_F(\theta)\, V_F, iC_F, i}{\sum_{i=1}^{m} w_F a_F(\theta)\, V_F, i}, \quad (30)$$

where the weights w_F and then part set volumes V_F are given by

$$w_F = w_g, w_h, k,$$
$$V_F = V_g, V_h, k. \quad (31)$$

6. Results and Discussions

We carried out the experiments using MATLAB 2013, by simulating the source and assertion information. We evaluated the results by using extensive simulations by generating up to 100 sources and 1000 assertions. Experiments were carried out to verify the accuracy and correctness of the probability that a given source is truthful or the given assertion is found truthful by the proposed Fuzzy Bayesian Scheme of interpretations. This technique is then compared with the existing methods like Page Rank and the results are tabulated. To test the results we randomly generated the source and assertions and partitioned these assertions into true and false. P_i is the random probability assigned to each source S_i generating L_i claims. Every claim has P_i probability of being true and $1 - P_i$ probability of being false. We compared the proposed Fuzzy Bayesian Interpretation scheme with that of the Page Rank algorithm. For every source correctness probability distribution, the results were averaged over 100 datasets in a time series. The number of true and false assertions was fixed as 1000 and the claims per source are set as 100. The total number of sources is initially set as 10 and is gradually moved towards 100. The prediction accuracy is shown in Figure 3. It was observed that the false positives and false negatives decreased with the increase in the number of sources. Relatively small error percentage of 5% to 8% was encountered by the source correctness probability. This probability is very accurate in the order of 0.1, when the large number of sources is considered. Figure 3 shows the graph between the prediction accuracy and the varying number of sources for prediction error of source probabilities, false positive of assertions, and false negative of assertions. We varied the count of true assertions to the overall total of assertions in the network and fixed the total number of assertions as 3000 and the number of sources as 30. The ratio of true to total assertions was changed from 0.2 to 0.8. It has been observed that the error of source correctness probability prediction decreases with the increase in the ratio of true assertions. Alternatively, the numbers of false negatives increase, as more and more true assertions are misclassified as false. Figure 4 shows the graph between the prediction accuracy and the varying number of assertions for prediction error of source

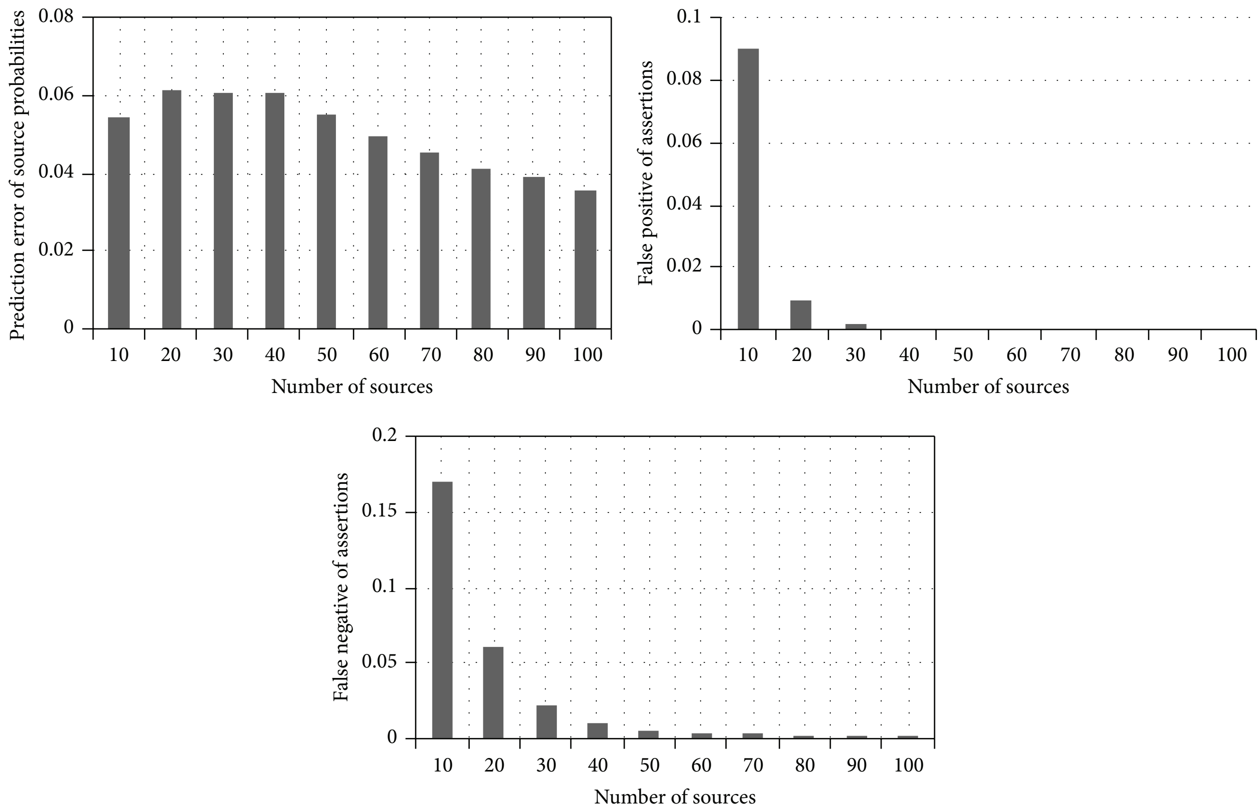

Figure 3: Prediction accuracy versus varying number of sources.

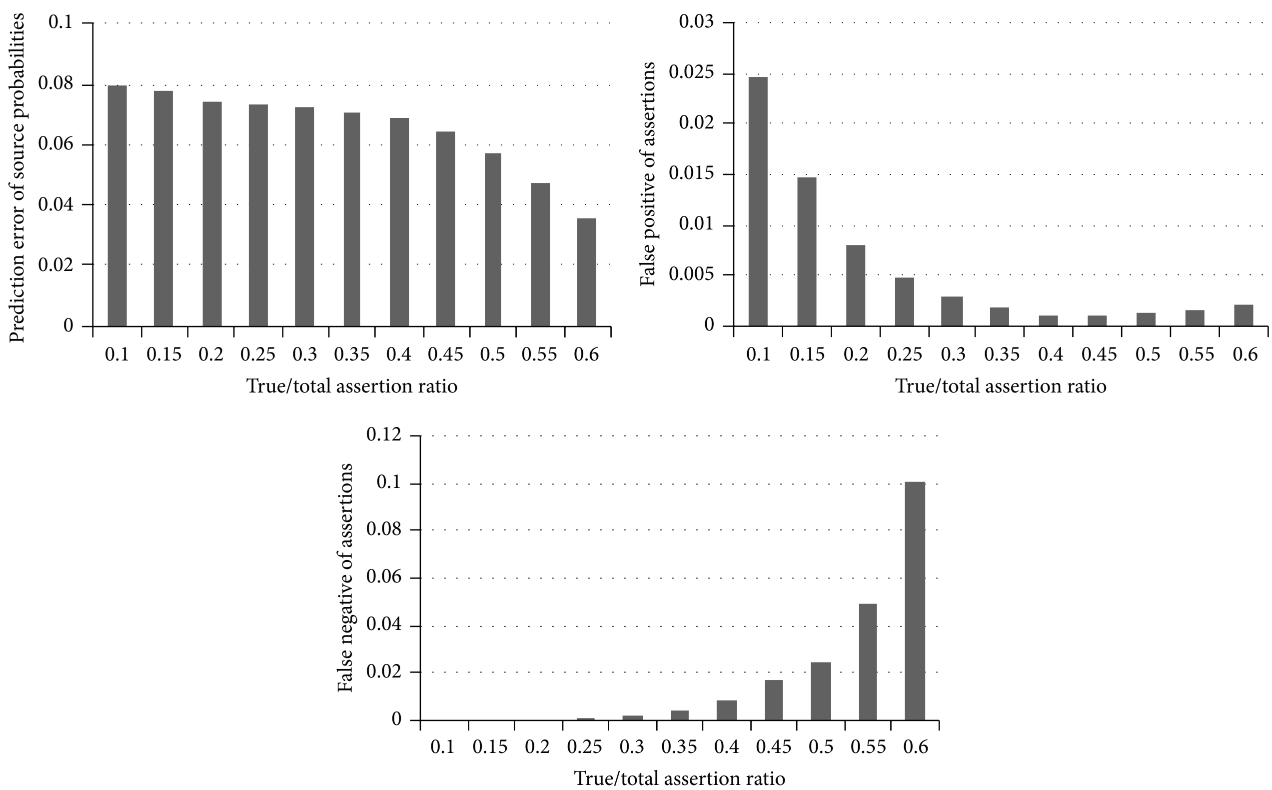

Figure 4: Prediction accuracy versus varying number of assertions.

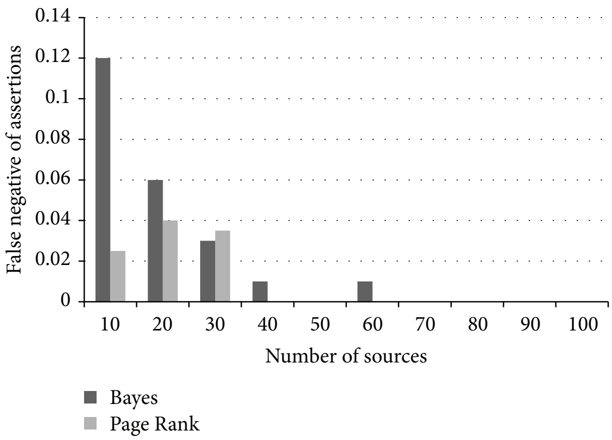

FIGURE 5: Prediction comparison.

probabilities, false positive of assertions, and false negative of assertions. At last, these results are compared with the Page Rank algorithm and the results are displayed as graph. The results show that Fuzzy Bayesian Interpretation outperforms the Page Rank algorithm for the given number of sources and the same has been shown in Figure 5. The observed results have confirmed the advantages of Fuzzy Bayesian approach over the conventional Bayesian analysis [24] in comparison with Page Rank.

7. Conclusion

In this research, an analysis of information networks was presented using the Fuzzy Bayesian approach and it has been successfully verified to assess the creditability of sources and assertions. Though several rank based algorithms are present, this paper converted the rank to a fuzzy probability method to find the truthfulness of a source and its assertion. With the ever ending increase in the smart devices under the category "Internet of Things," today's businesses have understood the importance of Big Data as they have opened up new frontiers in the field of business intelligence. Traditionally business intelligence adopted a revolutionary approach by bringing in the Big Data in Hadoop based environments and deriving the reporting, modelling, and prediction systems. Now, the businesses are moving towards evolutionary approaches or even hybrid approaches that use the combination of techniques of Big Data and business intelligence. With the Big Data becoming the primary input for business intelligence tools, social sentiment analysis and usage patterns form the backbone to market any product across the world leading to the concept of social sensing. This is a rapidly developing technology and, with the ever increasing mobile devices proliferation, this technique gains momentum. With the miniaturization of the sensors and the ease with which they are embedded into mobile devices, social sensing will definitely have a widespread acceptance and usage. Though the mobile device and the associated sensors possess high degree of reliability, when humans act as the operators of these sensors, the reliability becomes a question mark. Hence several researches similar to the one presented in this paper are being conducted across the world to improve the veracity of the Big Data. With the explosion of Cloud Computing, the concept of Cloud supported analytics has already evolved and is becoming multidimensional [26]. This new paradigm enables the infrastructure to scale up or down dynamically, adapting the system to the actual demand. Analytics as a Service (AaaS) or Big Data as a Service (BDaaS) is another budding area which is quite interesting and can take us towards ultimatum. Though the present study has incorporated only the Fuzzy Bayesian and Page Rank algorithms, future studies can be done using several advanced techniques like Maximum Likelihood Estimation and Expectation Maximisation to bring in more reliability in an undependable system.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Predicting Defects Using Information Intelligence Process Models in the Software Technology Project

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A key differentiator in a competitive market place is customer satisfaction. As per Gartner 2012 report, only 75%–80% of IT projects are successful. Customer satisfaction should be considered as a part of business strategy. The associated project parameters should be proactively managed and the project outcome needs to be predicted by a technical manager. There is lot of focus on the end state and on minimizing defect leakage as much as possible. Focus should be on proactively managing and shifting left in the software life cycle engineering model. Identify the problem upfront in the project cycle and do not wait for lessons to be learnt and take reactive steps. This paper gives the practical applicability of using predictive models and illustrates use of these models in a project to predict system testing defects thus helping to reduce residual defects.

1. Introduction

A project is temporary endeavor with defined objectives. Project management involves managing the project throughout the life cycle. Project life cycle includes initiation phase, planning phase, executing phase, monitoring and control phase, and finally closedown phase. The challenge lies in understanding and meeting the project goals with the defined project constraints. Every project is unique and needs to be planned well. A project has a defined start and end date. Project management is applicable across industries like production, information technology, and textile to name a few. In the information technology industry, project management plays a crucial role. Industry experts have highlighted the importance of project management. 20%–25% of IT projects fail due to poor project management. Project management principles need to be understood well by the technical managers. Proactive management is the key for success of any project. Ability to predict project outcomes and take preventive actions will determine the success of the project. The focus on shifting left in the project life cycle is vital. Self et al. [1] highlighted the importance of customer satisfaction measurement. Johnson and Gustafsson [2] and Peppers and Rogers [3] studied how customer satisfaction can be improved and customer relationship managed using strategic frameworks. McConnell and Huba [4] discuss how loyal customers become a volunteer sales force.

Shift left approach is one of the approaches where the focus is to concentrate on the upstream activities. The intent is to reduce the defect leakage upfront such that there is less impact on downstream activities. This approach is applicable for any type of industry. In a software development project, the shift left refers to section of quality management concerned with prevention planning. Designing the shift left strategy is important. Focus should be to improve overall operational efficiency and ensure early defect detection while reducing risks and costs. The process phases for a typical software life cycle project are definition phase, design phase, development phase, test phase, and finally deployment phase. A management layer ensures these processes are followed as planned. Shift left strategy needs to be inbuilt in this process so that the technical manager can identify defects upfront.

Stoddard [5] highlighted the importance of process performance models and its reliability in software projects. Gummeson [6] highlighted the use of qualitative methods in managing research. Breyfogle III [7] discussed implementing six sigma qualitative methods. Venkatesh et al. [8, 9] highlighted the importance of process performance models to improve customer satisfaction. Client objectives should be translated into quantitative objectives. These objectives should then be converted to project goals. For each of the goals based on the contract, the service level agreements should be tabulated. Technical manager can review these goals and go with client goals or if organizational goals are even stringent, manager can set that as the project goal. After the goals are clear, operational definition for each of these goals should be documented and agreed upon. This should also include the metric, measures, collection mechanism, and frequency of collection. Kan [10] explains the importance of measures and metrics. Remenyi et al. [11] studied the effective measurement of IT costs and their benefits. As part of measurement, process and product measures need to be considered. Influencing factors for these measures should then be identified. Based on the measures and influencing factors, predictive models can be built to predict project outcomes. Coghlan and Brannick [12] explained the importance of research analysis in the organization using project outcomes. CMMI [13, 14] and Capability Maturity Model explain in detail about the capability models. Kulpa and Johnson [15, 16] explain the importance of CMMI as a process improvement approach. Prediction models can be used to predict interim and final outcomes. Influencing factors can then be modified to analyze the impact and determine actions to be taken. Stutzke [17] highlighted the importance of estimation in software intensive systems.

2. Defect Prediction Model

System testing is an important phase in project development life cycle. At this phase, systems are tested extensively. This also includes the integration of systems. For a technical manager, overall testing defect density is an important parameter to track. The number of defects identified during system testing determines the quality of the development. Project subject matter experts identify the different parameters that influence the system testing defect density through brainstorming session. Based on the influencing factors, the key ones that impact the system testing defect density are chosen. Then the operation definition, metrics, and measures are arrived at. Project data was collected for these parameters. Linear regression was performed against the data to find out the key variables that influence the overall testing defect density. After many trial and error methods the two variables below were established as the X factors.

With normal data, collected for outcome and the contributing factors, regression equation can be arrived at. Referring to the theory behind regression equations, it can be well understood that the equation depicts the most accurate mode. The fundamentals of regression equation aim at minimizing the sum of squared errors to zero:

$$\frac{d\,(\text{sse})}{da} = 0, \quad \frac{d\,(\text{sse})}{db} = 0, \quad \frac{d\,(\text{sse})}{dc} = 0, \tag{1}$$

where sse is the sum of squared error

$$\left[y_i - \left(ax_1 + bx_2 + c\right)\right]^2 = 0. \tag{2}$$

(1) Y is overall testing defect density—number of defects identified in system testing of the project against effort spent during testing phase of the project.

(2) $X1$ is technology experience—average relevant technology experience of the team, in person months.

(3) $X2$ is design review issue by size—number of design issues identified in the design phase of the project against the size of requirements measured in function points.

Correlation matrix between the variables is determined using R [18], a statistical tool.

3. Defect Density Regression Equation

The project data collated for the X and Y factors are as shown in Table 1. Data points from 25 projects in an organization were collected and considered for analysis. The nature of projects selected was large scale IT projects developed under Microsoft C# platform. Attributes such as number of lines of code written, number of defects, and number of human hours spent in the project were collected. The types of defects are lack of domain knowledge, improper algorithm, ambiguity in requirement documentation, incorrect usage of design tool, limitations of GUI controls, and so forth. Defect density is defined as follows:

$$\text{Defect Density (DD)} = \frac{\text{Number of defects}}{\text{Number of lines of code}}. \tag{3}$$

The project data collated for the X and Y factors are as shown in Table 1. Data points from 25 projects in an organization were collected and considered for analysis. Projects factored in were similar in nature. The null hypothesis considered is that $X1$ and $X2$ have no influence over Y (i.e., technology experience and design review issues by size do not impact system testing defect density). No mirror pattern can be found in Figure 1 and hence no heteroscedasticity is found. The normal probability plot as shown in Figure 2

Table 1: Project data values.

Y Overall testing defect density	$X1$ Technology experience (in months)	$X2$ Design review issues by size
0.101	32	82.000
0.110	36	72.000
0.090	34	80.000
0.113	33	73.000
0.124	26	55.000
0.123	22	62.000
0.134	23	66.000
0.142	34	69.000
0.125	36	68.000
0.151	19	65.000
0.099	35	90.000
0.020	41	90.000
0.031	43	92.000
0.018	50	93.000
0.073	41	90.000
0.074	43	89.000
0.121	36	74.000
0.113	30	82.000
0.121	24	56.000
0.332	7	43.000
0.520	8	32.000
0.490	9	22.000
0.099	42	97.000
0.085	39	87.000
0.650	11	22.000

Table 2: Regression equation.

Intercept	Technology experience (in months)	Design review issues by size
0.6233	−0.0004	−0.0064

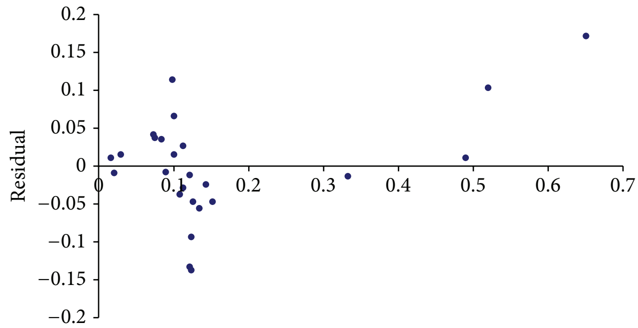

Figure 1: Residual plot.

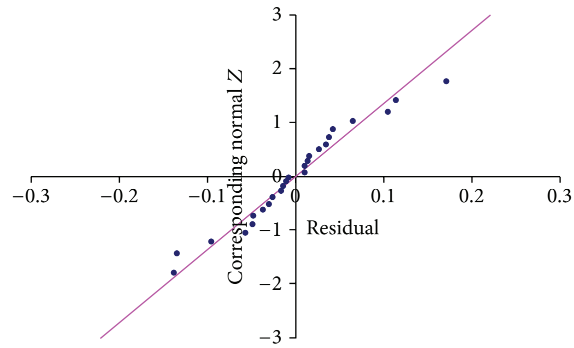

Figure 2: Normal probability plot.

is approximately linear. From the figure it is clear that the normality assumption for the errors has not been violated. With regard to the p value, since it is 0.0001 (<0.05), the null hypothesis is not valid, which means the variables selected have an impact on overall defect density.

As shown in Table 2, technology experience has a negative influence on overall defect density. As the team's technology experience increases, there are less project defects and hence the overall testing defect density is reduced. The influence of design review issues by size is negative. This means that when the values of design review issues by size are high the overall defect density will be low and vice versa. The more design issues are resolved, the lesser the probability of defect injection is.

The data proves that the overall testing defect density is influenced by design subprocess and technology experience. Project quality group in the organization shares the baseline data for these variables. For each subprocess, based on the type of project, the organization values can be considered. The technical manager can then use these reference values to determine the upper specification limit and lower specification limit for the project. These values will be available for each subprocess parameter. The technical manager can determine which subprocess he would like to control and select the threshold values based on that. For example, in design process, high level design subprocess, organization value might recommend 92% as the baseline value. Mishra et al. [19] explained the process to establish the process performance baseline. Technical manager might decide to refer to this and make it more stringent and use 95% as the baseline value. Based on the current project context, the other subprocess parameters and technology experience values can be considered for prediction.

Based on the selected threshold values, what-if analysis is performed. Going by the process subparameters and their values, overall testing defect density is predicted. The predicted outcome is then compared with the thresholds. Based on the gap, subprocess parameters are further tweaked to understand the variation. It is important to note that while changing the parameters, the technical manager should understand the practical implication in the project. It is not only about the mathematical model, but also about how it can be put in practice. For example, if, based on the prediction model, the team average technology experience is expected to be around 60 months, then the technical manager has to look at the project constraints. So, though the prediction model considers the key influencing factors to predict the overall defect density, the influencing factor values might have an impact on project schedule and project cost, which need to be analyzed.

Technical manager might decide to adjust the predicted outcome based on the project constraints. At every step, the manager should document the assumptions, risks, and mitigation plans. Detailed defect prevention plan should be in place. At every step, the defect, its type, cause, preventive action, owner, and target date should be documented. Thus at every step the quality gates are important. Quality gates need to be defined at every phase in the project life cycle. The quality gates need to be reviewed and approved by the technical manager. Process quality manager should also review these quality gates and suggest improvements if need be. Different root-cause analysis techniques like 5 whys can be used to pin down the root cause. After identifying the root cause the next steps in terms of corrective and preventive actions should also be thought through. It is recommended to have process quality experts review these plans so that they can bring in their experience and highlight any improvements in these plans.

As shown in Table 4, b is the coefficient and gives the least squares estimates. $s(b)$ gives the standard errors of least square estimates for the x-variables. t gives the computed t-statistic. This is the coefficient divided by the standard error. p value gives the p value for test of hypothesis. Variance inflation factor (VIF) quantifies the severity of multicollinearity in an ordinary least squares regression analysis. VIF for the given data is 6.43.

In requirements phase of project life cycle, shift left approach can be implemented. Shift left testing is a powerful and well-known trend within the software testing community that is largely intended to better integrate testing into the system/software engineering and thereby uncover defects earlier when they are easier and less expensive to fix. There are four basic ways to shift testing earlier in the life cycle, they are traditional shift left, the incremental shift left, Agile/DevOps shift left, and model-based shift left. The shift left model accelerates the attention to quality from the inception of the project, which increases the ability to discover and correct defects when they occur.

In requirement phase, few process steps that can be added are requirement harvesting, requirements review by the right stakeholders, and requirements testability. Requirement harvesting is about not only getting the requirements from the end user and setting them at baseline, but also diving deep into the requirements. Requirements should be explored and understood in detail to understand the business context and objectives clearly. Requirement review is a process that is crucial and it is important to bring the right stakeholders from the business and user community to validate the requirements. From the given requirements it is important to break them down to testable requirements. Of these requirements, identify those which can be tested individually or as a group or those that cannot be tested. This phase is the first step and it is crucial to do it right. The focus is to detect defects early in the life cycle. Test driven development plan should be the focus in design phase. New project development models talk about test driven development. Test cases are written, executed, and based on the failure of the test cases; codes are developed and tested again. Smoke testing and test environment validation need to be included before testing starts. Root-cause analysis at every stage is vital to look at the corrective and preventive actions. These actions need to be implemented to avoid defect leakage and reoccurrence of defects. Technical managers need to be aware of these process improvement activities and implement them in the project. Process quality consultants play a vital role in training the technical managers with relevant case studies so that they can implement these improvement process steps.

Table 3: Multiple regression results.

Source	SS	df	MS	F	p
Regression	0.495	2	0.247	45.099	0.000
Error	0.1207	22	0.0055		
Total	0.6157	24			

Table 4: ANOVA table.

	Intercept	Relevant technology experience	Design review index
b	0.6233	−0.0004	−0.0064
$s(b)$	0.0539	0.0031	0.0018
t	11.55	−0.1227	−3.6321
p	0.0000	0.9035	0.0015

As shown in Table 3, SS is sum of squares due to regression and it is a measure of the total variation in y that can be explained by the regression with the x-variable. df is the degrees of freedom. MS is the mean square; it is a measure of sum of squares divided by the degrees of freedom. Mean square of regression (MSR) and mean square of error (MSE) are the two variables that define F.

Consider $F = \text{MSR}/\text{MSE}$. The F-statistic is used to test whether the y-variable and x-variable are related.

For the given data mean square of regression is 0.247 and mean square of error is 0.0055. F-statistic is 45 and the p value is zero. This provides existence of a linear relationship between overall testing defect density and the two-variable technology experience and design review issue. R^2 is a statistic that will give information about goodness of fit of a model. In regression equation, R^2 coefficient of determination is a statistical measure to determine how well regression line approximates to real data points. The adjusted R^2 is a modified version that adjusts the number of predictors in the model. For the given data, R^2 is 0.8309 and adjusted R^2 is 0.7861.

Prediction models should help the technical manager to predict the project outcomes. Project outcomes include schedule, costs, and defect parameters. A technical manager has to consider the project requirement, project context, and project constraints, to manage the project successfully. The most excellent approach to defects is to eliminate them as found. This can be only possible if defect prevention techniques and processes are used by the organization. The goal of defect prevention is to eliminate the defects altogether so that they cannot reoccur in the future. The primary objective of proactive defect management is to discover and resolve known defects as early as possible before the occurrence of any major problem related to them. Once the defects are discovered, try to eliminate every defect. For defects that cannot be eliminated try to reduce their impact. The reactive defect management process focuses on identifying the causes of underlying reported problem. A technical manager needs to be proactive in tracking project goals instead of being reactive.

Prediction models are statistical and simulative in nature. These models should help in simulating project scenarios and help in determining outcomes. It can model the different variation factors. These models help the manager with the predicted range or the variation of its outcomes. Based on the different project scenarios, the technical manager needs to perform "what-if" analysis. This analysis will help the manager to change the project parameters based on different scenarios and select the best option.

4. Building Quality Gates in Project Life Cycle

A typical software project development life cycle will go through requirements phase, design phase, development phase, unit testing phase, system testing phase, user acceptance testing phase, and finally implementation phase. Quality is an important project parameter at every phase in the life cycle. In the requirement phase, the technical manager needs to ensure that the scope of the requirements is thoroughly documented and signed off. Requirement traceability matrix needs to be created. Every requirement should be traceable as the project moves from one phase to the next phase. Adherence to change management process throughout the process is vital. Technical manager should ensure that change control board is formed during the project initiation phase itself. Requirement clarifications need to be tracked and closed. Requirement reviews should be formally signed off. During the design phase, design prototypes need to be prepared and validated with the user groups.

Design standards, templates, and tools need to be decided and used in the project to ensure compliance. Traceability of design modules to requirements is important. Build sequence needs to be factored as part of design process. The technical manager needs to ensure that coding standards are followed. Configuration management needs to be implemented. Organization configuration tool or client configuration tool can be utilized. Detailed configuration management process should be laid down. The technical manager needs to ensure that all the relevant stakeholders participate in design and code review process. It is recommended to use code review tools. Defect prevention plans need to be implemented.

Detailed test strategy and test plan should be laid down for system testing. Defect management process should be actively followed. Test case coverage is vital. Defect triage meetings are recommended for faster turnaround of defects. Entry and exit criteria at every testing phase should be called out and followed. The technical manager needs to ensure that all business scenarios are covered as part of test coverage. Clearly defined standards and procedures should be implemented. Periodic quality reviews and audits are recommended. The technical manager needs to conduct retrospective meeting and implement the preventive actions. A quality mindset with the project team and all relevant stakeholders is important.

5. Conclusion

In any business, customer defines the business. Customer satisfaction is vital for survival. In an IT organization, the customer satisfaction index is pivotal. Customers can make or break business. Customer can in turn act as brand ambassadors and recommend new business for the organization. The main parameters that influence customer satisfaction are faster time to market, quality, and cost. Based on the customer context, the priority of these parameters will change. Few additional parameters can get added. But, overall, cost, quality, and schedule set the base. These three parameters are again related to each other. As a technical manager it is important to understand the customer expectations and ensure that these critical parameters are managed well. Prediction models help in managing these parameters effectively. A manager can predict desired project outcome, perform scenario based analysis, and take right decisions to meet project goals. The practical case study demonstrated how the technical manager can predict overall testing defect density considering technology experience and design review issues by size. The usage of process steps such as prediction model, what-if scenario analysis, corrective and preventive actions, assumptions, and risks helps the manager to meet the project outcomes. Technical managers need to be trained on prediction models and should be comfortable to use these models effectively in projects. Shift left techniques determine the project success. Prediction models are not a one-time activity; it should be continuously used during the project life cycle.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Scalable Clustering of High-Dimensional Data Technique Using SPCM with Ant Colony Optimization Intelligence

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Clusters of high-dimensional data techniques are emerging, according to data noisy and poor quality challenges. This paper has been developed to cluster data using high-dimensional similarity based PCM (SPCM), with ant colony optimization intelligence which is effective in clustering nonspatial data without getting knowledge about cluster number from the user. The PCM becomes similarity based by using mountain method with it. Though this is efficient clustering, it is checked for optimization using ant colony algorithm with swarm intelligence. Thus the scalable clustering technique is obtained and the evaluation results are checked with synthetic datasets.

1. Introduction

Data mining deals with extracting useful information from datasets [1]. In data mining, clustering is a process which recognizes similar description (homogenized) groups of data on the basis of their size (profile). This involves a distance metric, in which the data points in each partition are similar to points in different partitions. A large number of data mining techniques to cluster the data are available. Few of them are CLARANS [2], Focused CLARANS [3], BIRCH [4], DBSCAN [5], and CURE [6]. Clustering is a technique that is required for various applications in pattern analysis, decision making, group and machine document retrieval, learning environment, pattern classification, and image segmentation. Clustering the dataset includes measures distance or similarity measure to partition the dataset, where data inside the clusters is similar to data outside the cluster.

The preprocessing steps are carried out before clustering, in which feature extraction and feature selection are major parts. This reduces the burden of clustering algorithm. The selection process is being done by eliminating the redundant ones. These techniques increase the speed of clustering algorithms and hence performance is improved [6]. Many feature selection techniques are proposed in the literature to reduce the size of the dataset. In those cases, reducing the dimensions using conventional feature selection leads to significant loss of data. In traditional clustering algorithm, the clustering algorithm follows distance function, but the distance function used by the algorithms to all aspects of equal treatment is not of equal importance. Where the selection of feature techniques reduces dimensions by removing irrelevant features they may have to eliminate many of the features associated with the presence of sporadic failure. For this a new class of projected clustering arises in this technique.

A projected clustering is also called subspace clustering [7] which has high-dimensional datasets, a unique group of data points that are correlated with different sets of dimensions, where the focus is to determine a set of attributes for each cluster. A set of relevant features shows the accuracy of the cluster, which has potential applications in e-commerce [8], a computer vision task [9]. There are various approaches proposed for projected clustering in the past. Few of them are CLIQUE, DOC, Fast DOC, PROCLUS, ORCLUS, and HARP [10]. After the clustering process in data mining, there is a need to check whether it is an optimized technique or not. There are various optimization techniques in queue, in which the ant colony cluster algorithm uses the characteristics of positive feedback, which is a good convergent parallel algorithm.

2. Related Works

A projected hierarchical clustering algorithm called hierarchical approach with automatic relevant dimension selection (HARP) is proposed in [10]. HARP works with the assumption that if the data points are similar in high-dimensional space, they also show the same similarity in lower-dimensional space. Depending on this criterion, if clusters are similar in various numbers of dimensions, they are allowed to merge. The similarity and minimum number of similar dimensions can be controlled dynamically, without the help of parameters given by user. The advantage of HARP is that it determines automatically the dimensions for each cluster without the use of input parameters, whose values are difficult to define. HARP [11] also provides interesting results on gene expression data.

The efficiency of DOC/FastDOC has been studied using FPC in [12] and has proved that it is much faster than the previous method, which also has some drawbacks, such as FPC that fits well when the cluster is in the form of a hypercube with parameter values clearly specified. A type of density based clustering algorithm for projected clustering is proposed in [13], which uses histogram construction known as efficient projective clustering by histograms (EPCH). Dense regions are spotted in each histogram by lowering threshold iteratively; for each data point corresponding to a region in a subspace a signature is generated. By identifying signatures for a large number of data points [13], projected clusters are uncovered. EPCH is a type of compression based clustering algorithm; it is faster and can handle irregular clusters, but in full-dimensional space it cannot compute distance between data points. Fuzzy clustering method (FCM) [14] is based on partition. FCM's main disadvantage is that it features the request for the number of clusters to be generated. In addition, when the data affected by noise is high, it can lead to clusters of poor quality because FCM is highly sensitive to outliers. Prediction in mobile mining for location based services to determine precious information is studied by Venkatesh et al. [15]. Clustering nonspatial data using similarity based PCM (SPCM) is proposed in [14].

3. Proposed Methodology

The proposed methodology is focused to cluster high-dimensional data in projected space. The main idea behind the development of PCM SPCM based application is to integrate with mountain cluster. SPCM has merit that it can automatically produce results clustering without requiring users to determine the number of clusters. Though this is efficient clustering, it is checked for optimization using ant colony algorithm with swarm intelligence. Thus the scalable clustering technique is obtained and the evaluation results are checked with synthetic datasets. This work is done based on the block diagram shown in Figure 1.

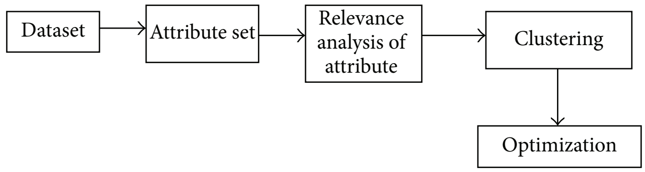

Figure 1: Block diagram of proposed methodology.

Let the dataset be taken as DS, having d-dimensional points, where attributes are denoted as $D = \{D_1, D_2, \ldots, D_d\}$. Then N data points are initialized as

$$Y = \{y_1, y_2, \ldots, y_N\}, \quad \text{where } y_i = y_{i1}, \ldots, y_{ij}, \ldots y_{id}. \quad (1)$$

In this, each y_{ij} ($i = 1, \ldots, N$; $j = 1, \ldots, d$) corresponds to the value of y_i data point on D_j attribute.

The cluster will see a considerable number of aspects related to the above relationship in which points are close to each other in a large number. The three main steps are as follows:

(i) attribute relevance analysis,

(ii) clustering,

(iii) optimization.

3.1. Attribute Relevance Analysis. In attribute relevance analysis, cluster structures are displayed by identifying dense regions and their location in each dimension. For projected clustering, a cluster must contain relevant dimensions of the data in which the projection of each point of the cluster is close to a sufficient number of other projected points. The dimensions identified represent potential candidates for the clusters. Using the cluster structure, a region having high density of points is chosen compared to its surrounding regions, which represent the 1D projection of clusters. By detecting dense regions in each dimension the discrimination between dimensions that are relevant and irrelevant can be detected, and sparseness degree is then computed to detect densely populated regions in each attribute.

3.2. SPCM Based Clustering. After the completion of the first step, the dimension of dataset is given for reduction. It incorporates outlier elimination using sparseness estimation and similarity based possibility C-means (SPCM) algorithm. Spatial data [16] defines a location, shape, size, and orientation and it includes spatial relationships whereas nonspatial data is information which is independent of all geometric considerations. In general spatial data are multidimensional and autocorrelated and nonspatial data are one-dimensional and independent. After identification of clusters, by selecting appropriate dimensions the result is refined. The advantage of PCM is the membership function and the number of clusters is independent, and in a noisy environment with outliers it is highly vigorous [4]. When the data is a set of samples drawn from stationary processes, a framework for defining consistency of clustering algorithms is proposed in [17]. An absolute degree of data object and membership function in a cluster is assumed. There is no dependency for the membership degree on the same data objects in other clusters. So they are independent in this technique, as given in

$$U_{ip} = \frac{1}{1 + \left(d_{ip}^2/\eta_i\right)^{1/(m-1)}}, \quad (2)$$

where u_{ij} is the membership degree for object and d_{ij} is the Euclidean distance between object x_j and prototype v_i. The parameter η_i determines the distance of membership function equals 0.5. It can be expressed as

$$\eta_i = P\frac{\sum_{p=1}^{N} u_{ip}^m d_{ip}^2}{\sum_{p=1}^{N} u_{ip}^m}, \quad (3)$$

where P is assigned to a value of one. The prototype for inner product distance measure is as given in

$$v_i = \frac{\sum_{p=1}^{n} u_{ip}^m x_p}{\sum_{p=1}^{N} u_{ip}^m}. \quad (4)$$

This algorithm follows the proceeding steps.

Step 1. A number of clusters are fixed c; fix $1 < m < \infty$; set iteration counter $l = 1$; initialize possible c-partition $U^{(O)}$; then estimate η_i.

Step 2. Update the prototypes $V^{(l+1)}$ using $U^{(l)}$.

Step 3. Compute $U^{(l+1)}$ using $V^{(l+1)}$.

Step 4. Consider $l = l + 1$.

Step 5. If $|U^{(l+1)} - U^{(1)}| < \varepsilon$, then process stops; else go to Step 2.

3.3. Mountain Method. Yager and Filev [18] proposed the mountain method which is applicable for searching approximate centers in the cluster, where the maximum of density measures are located. In Algorithm 1 one cluster is identified at a time and it is removed by eliminating density based function for other points.

In m-dimensional space, R^m, n data points are chosen as $\{x_1, \ldots, x_n\}$. Let x_{pj} denote the jth coordinate of the pth point, where $p = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$. Mountain method discretizes the feature space which forms an m-dimensional grid in hypercube $I_1 \times \cdots \times I_m$ with nodes $N_{(i_1,\ldots,i_m)}$, where $i_i, \ldots, i_m$ chooses values from the set $[1, \ldots, r_1], \ldots, [1, \ldots, r_m]$. The intervals I_j are used to define the range of coordinates x_{pj}, where the intervals I_j are discretized into r_j equidistant points.

The mountain function is calculated for the vertex point V_i defined as given in

$$M^1 (V_i) = \sum_{p=1}^{n} e^{-\alpha d(x_p, v_i)}, \quad (5)$$

where $d(x_p, V_i)$ is the distance from the data point x_p to the grid nodes V_i and α is the positive constant. The cluster centers are selected by the nodes having the maximum number of mountain functions. To find the cluster centers the mountain function is defined as given in

$$M^p (V_i) = M^{p-1} (V_i) - M'_{p-1} \sum_{p=1}^{n} e^{-\beta d(x_{p-1}, v_i)}, \quad (6)$$

where M'_{p-1} is taken as the maximal value of mountain function and M_{p-1} and β are positive constants.

3.4. Ant Colony Optimization Based on Swarm Intelligence. The optimization algorithm is designed in such a way that probability function is used as basic pick-up and pick-down. This creates increase in similitude degree of system and maximizes the system's average similitude degree. Dorigo and Socha [19] who proposed ant colony system solve combinatorial optimization problems. Ant colony cluster [20] is motivated by the accumulation of ant bodies and ant larvae classification. The ant colony cluster algorithm uses the positive feedback characteristics. The ant conveying process is followed as the main process in the ant cluster algorithm. To convey the object to the destination, the ant considers the equivalent degree between the current object and the surrounding objects; by this way the ant will not know the other ant's location distributing load status.

Thus the ant conveying process is a simple, flexible, easy, and absolute individual behavior where objects are distributed and divided into several clusters during long time, subsequently as a concurrent process. The ant's observing radius is the main factor that influences this process, and the cluster is more efficient when radius is small [4]. Many isolated points are created, where the combination of the clusters is influenced when the observing radius is too small, which cause the inefficiency of the cluster capability. When the observing radius is large, the algorithm's convergence speed in return is expedited. The main advantage of traditional ant cluster algorithm is the adjustment of observing radius and the ant's "memory" function, and it also benefits in magnitude ameliorating aspect.

4. Experimental Results

The experiment is evaluated using the synthesis dataset implemented in MATLAB R2012 platform. The evaluation of this work is compared with existing method of PCKA for WDBC and MF, and the two datasets WDBC and MF are chosen because they are real and synthetic datasets. The performance results are evaluated using clustering accuracy and immunity to outliers.

Table 1 shows the clustering accuracy of the proposed and existing technique for the WDBC and MF dataset. The proposed technique achieves higher accuracy for both datasets when compared with existing PCKA technique. The reliability of PCKA technique is 90%.

Figure 2 shows the immunity of outlier for the 2 percent of d, where the existing technique PCKA is affected more

```
For every item D_i do
        Place D_i randomly on grid
End For
For all ants do
        Place ant at randomly selected site
End For
For t = 1 to t_max do
        For all ants do
            If ((ant Unladed) & (site S_j occupied by item D_i)) then
                Compute the similarity f(D_i) of D_i in A × A
                Calculate the R_R and generate a random number P
                If R_R > P then
                  Pick up item D_i
                  Takes the f(D_i) and current position
                  Move the ant with the item D_i to random site.
                Else
                  Move the empty ant to random site
                End If
           Else if ((agent carrying) and (site empty)) then
                Compute the similarity f(D_i) of D_i
                Calculate the R_R and generate a random number P
                If R_R > P then
                  Drop item
                End If
           Else
             Move to a randomly selected neighboring site
           End If
        End For
        If ((t > 0.5t_max) and (if t attains radius change condition)) then
           Reduce the radius
         Clusters are generated iteratively and cluster centers are calculated
         Connect the obtained clusters with the same cluster center
         With Poor Similarity Relocate the Items
       End If
End For
Print location of items.
```

Algorithm 1: Ant colony optimization algorithm.

Table 1: Accuracy of clustering.

Dataset	Proposed	Existing PCKA [4]
WDBC	94.52	91.56
MF	93.7	90.45

when compared with proposed technique and Figure 3 shows the immunity of outlier for the 30 percent of d, where the existing technique PCKA is affected more when compared with proposed technique.

5. Conclusion

An efficient high-dimensional dataset clustering is proposed in this work with its optimized results. The results were analyzed through performance evaluation based on real datasets which are synthetic. Here the SPCM method has shown its excellent performance for similarity based clustering in terms of quality, though the noisy environment dealt with outliers.

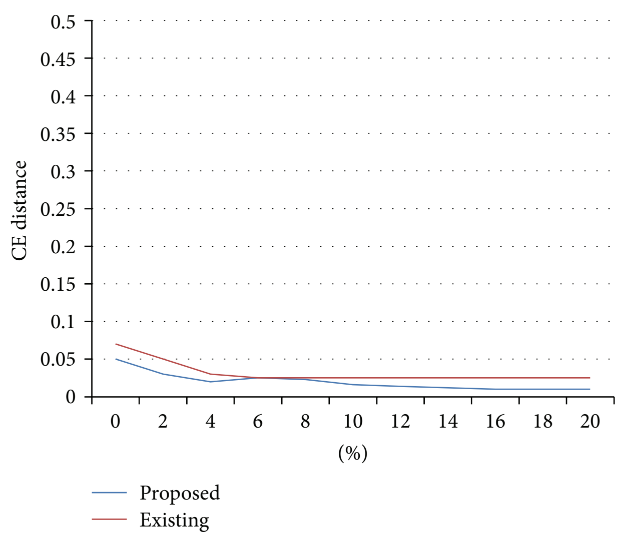

Figure 2: Immunity to outliers for datasets with $l_{\text{real}} = 2$ percent of d.

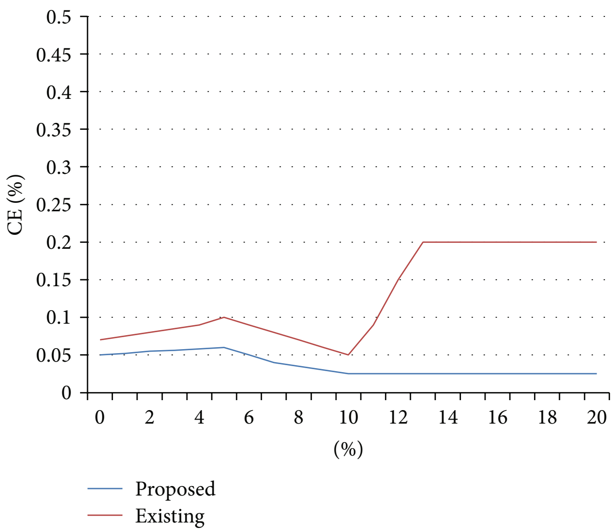

FIGURE 3: Immunity to outliers for datasets with $l_{\text{real}} = 30$ percent of d.

This solves the problem of other fuzzy clustering methods which deals with similarity based clustering applications in the sets. This work is composed of SPCM technique which finds the clusters automatically without users input of number of clusters. And the optimized clustering result is obtained by using ant colony optimized technique with swarm intelligence. It is robust and helps to produce scalable clustering. The results given in the above section show its efficient clustering accuracy and outlier detection. The scope of further research is to deal with datasets that have a large number of dimensions.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Energy Efficient Cluster Based Scheduling Scheme for Wireless Sensor Networks

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The energy utilization of sensor nodes in large scale wireless sensor network points out the crucial need for scalable and energy efficient clustering protocols. Since sensor nodes usually operate on batteries, the maximum utility of network is greatly dependent on ideal usage of energy leftover in these sensor nodes. In this paper, we propose an Energy Efficient Cluster Based Scheduling Scheme for wireless sensor networks that balances the sensor network lifetime and energy efficiency. In the first phase of our proposed scheme, cluster topology is discovered and cluster head is chosen based on remaining energy level. The cluster head monitors the network energy threshold value to identify the energy drain rate of all its cluster members. In the second phase, scheduling algorithm is presented to allocate time slots to cluster member data packets. Here congestion occurrence is totally avoided. In the third phase, energy consumption model is proposed to maintain maximum residual energy level across the network. Moreover, we also propose a new packet format which is given to all cluster member nodes. The simulation results prove that the proposed scheme greatly contributes to maximum network lifetime, high energy, reduced overhead, and maximum delivery ratio.

1. Introduction

Wireless Sensor Networks. A wireless sensor vetwork (WSN) comprises a large number of nodes either deterministically or deployed in a random manner, for instance, from an aircraft, to observe the environment. Sensor nodes communicate with each other by multihopping, that is, by using other sensor nodes in the network as relay nodes. In most applications, all the sensor nodes are required to transmit their data to a special node termed base station or sink which links the sensor network to the end-user, for instance to an airplane crossing the network area. Sink is assumed to have enormous energy resources, complicated processing and extreme transmission range capabilities together with adequate memory. One of the most important issues regarding the design of sensor networks is power consumption since these networks consist of sensor nodes densely deployed in hazardous and remote areas where the replacement of batteries is impossible. The major portion of energy is consumed during data transmission and reception. All these generic network operations together with the underlying computational operations also contribute to the energy utilization.

Need for Scheduling in WSNs. The WSNs comprise a collection of sensor nodes. Every one of these has an implanted processor, a radio, and one or more sensors. These nodes operate together in the area being observed and gather physical quantities of the environment, such as temperature or humidity. Information sensed by these sensor nodes can be utilized by different high level applications such as habitat monitoring, surveillance systems, and across systems monitoring various natural phenomena. Sensor nodes have restricted battery life. Most applications rely on the sensors deployed in hard-to-reach areas. In such scenarios, it is unrealistic for any kind of manual intervention to replace battery. The probability of these dispensable sensor nodes to stay alive within the network is based on their energy depletion levels. Hence the sensor network nodes are expected to manage themselves on their energy constrained battery resources. In the absence of optimal power management, the sensor nodes are believed to have a minimum lifetime.

Inherently, grouping sensor nodes into clustershas been widely adopted to achieve high energy efficiency and in turn to prolong network lifetime in large scale WSN environments. The proposed Energy Efficient Cluster based Scheduling Scheme (EECSS) implies cluster based organization of the sensor nodes in order that cluster head (CH) selection considering the residual energy parameter is made possible, thus leading to significant energy savings. The network structure allows each cluster to have regular sensor nodes as members and a cluster leader, which is also called the CH and quiet naturally performs the special scheduling tasks across the clustered sensor networks. CH nodes perform data aggregation and transmit them to the base station; hence they are expected to expose higher energy drain rates due to their excessive transmissions to remote locations at farthest proximities. The EECSS attempts to balance the energy consumption among all the network nodes, by periodically reelecting new CHs over time in each cluster across the network. Also the CH monitors the cluster members for their drain rates and based on it they are scheduled for each round of communication. The scheduling algorithm presented also allocates different time slots for the cluster members to send their energy information and actual data information to their corresponding CHs.

The need for clustering in WSNs is motivated in Section 1 and a briefing on the sensor network pattern is given. The state of the art in corresponding cluster based scheduling approaches for large scale WSN environment is presented in Section 2. Also the existing design challenges are explored. In the main body of the paper, that is, Section 3, the implementation methodologies for the proposed EECSS are discussed. The analysis of the experimental settings and results are discussed in Section 4. Finally the paper concludes with Section 5 stating various general comparisons between the proposed and existing methodologies.

2. Related Work

The Long-Lifetime and Low-Latency Data Aggregation Scheduling (L4DAS) algorithm [1] is proposed to build a degree-bounded least height spanning tree as an aggregation tree which provides an extended network lifetime. A maximum impedance priority scheduling algorithm is introduced to organize the transmission of nodes in such a way the latency is minimized considerably.

With reference to [2], a novel distributed Power Scheduling (PS) algorithm is presented for stationary continuous monitoring sensor networks. This scheme takes advantage of the time scale distinction between sensor network reconfiguration periods and data transmitting periods. The approach is distributed and works in a well-blended cooperation with well-defined sensor network routing and MAC layer protocols. However the approach hardly fits into any one layer, as it requires the joint effort of both the routing and MAC layers.

An Energy Efficient Distributed Schedule-Based (EEDS) protocol [3] is introduced for applications with periodic data traffic. The EEDS insists that the time frame be composed of rounds. Each round comprises three phases. In the first phase, an energy-aware tree is built, and then a TDMA schedule is constructed in a distributed fashion in the second phase. In accordance to the built schedule, the nodes are subject to data transmission in the final phase. At the mere initiation of each round, the tree is rebuilt and a fresh TDMA schedule is constructed.

The Packet Scheduling Algorithm (PSA) [4] is employed to lessen the packet congestion in MAC layer that ultimately reduces the overall packet collision in the network system. The algorithm allows scheduling ofall packets from application layer and network layer to reduce network congestion which in turn prevents packet collision across data link layer. The PSA implementation proves to minimize packet collision with an exponential increase in throughput as a by-product.

The Deadline Aware Energy Efficient Query Scheduling (DAEEQS) algorithm [5] is identified to be suitable for location-based queries in WSNs with mobile sinks. This scheduling algorithm aims to escalate the rate of successful queries and to curtail the energy expenditure of sensors with multihop communication that exploits deterministic sink mobility. For this reason, prior to query submission, the scheduling algorithm makes choice of the release and collects sensors such that two important performance criteria are met: the energy requirement for data forwarding is minimal and the response time meets the deadline specified.

The Mobile Element Scheduling (MES) cited in [6] outlines a scheduling problem where a mobile element needs to visit the sensor nodes so that none of their buffers overflow. It is proved to be NP- complete. It concludes with significant heuristics that prove that the Minimum Weighted Sum First algorithm performs extremely well and is computationally inexpensive. In addition it was formulated to adapt node failures.

The Efficient Scheduling for the Mobile Sink in Wireless Sensor Networks with Delay Constraint (ESWC) states unified framework [7] to analyze the sink mobility problem in WSNs with delay constraint. A mathematical formulation that jointly considers the issues of sink scheduling, data routing, bounded delay, and so forth, is depicted. A set of subproblems and optimal solutions are discussed. Finally the algorithm attempts to generalize the solutions and proposes a polynomial-time optimal approach for the origin problem.

An energy efficient scheduling technique [8] that addresses WSN environment in terms of lifetime maximization and delay is employed. In this paper, two optimization problems were focused. Firstly, when the wake-up rates of the sensor nodes are given, a distributed algorithm that minimizes the expected event-reporting delay from all sensor nodes to the sink is developed. Secondly, exploiting a specific definition of the network lifetime, lifetime-maximization problem is handled to optimally control the sleep-wake scheduling and the any-cast scheduling policies in order to maximize the network lifetime subject to an upper limit on the expected end-to-end delay.

In connection to the High Energy First (HEF) algorithm [9], the issue of predictability is addressed for WSNs of real-time interests. The HEF algorithm proves to be an optimal CH selection algorithm that maximizes a hard N-of-N lifetime. Also the paper concludes with theoretical bounds on the feasibility test for hard network lifetime with respect to the HEF.

The Balanced-Energy Scheduling (BS) scheme [9] is introduced in cluster based sensor networks. The aim of BS scheme is to evenly distribute the energy load of the sensing and communication tasks among all the nodes in the cluster, thereby extending the time until the cluster can no longer provide adequate sensing coverage. Two related sleep scheduling schemes, the Distance-Based Scheduling (DS) scheme and the Randomized Scheduling (RS) scheme, are also studied in terms of the coefficient of variation of their energy consumption.

The wireless sensor network lifetime is improved through Power Aware (PA) organization [10]. The problem of energy efficiency in wireless sensor applications is addressed for surveillance of a set of targets with known locations. It is considered that a large number of sensors are dispersed randomly at closest proximities to a set of objectives and the monitored information is sent to a central processing node. The principle behind that is that every target must be monitored at all times at least by one sensor and every sensor is able to monitor all targets within its operational range. The method proposed for extending the sensor network lifetime is to divide the set of sensors into disjoint sets such that every set completely covers all targets. As all targets are monitored by every sensor set; the goal of this approach is to determine a maximum number of disjoint sets, so that the time interval between two activations for any sensor is longer.

The Dynamic Conflict-Free Query Scheduling (DCQS) [11] presents a novel transmission scheduling technique specially designed for query services in large scale WSNs. The planner cuts down query latency by constructing transmission plans based on the precedence constraints with in-network aggregation. The scheduler enhances throughput by overlapping the transmissions of multiple query instances concurrently while enforcing a conflict-free schedule. Also it attempts to achieve a maximum query rate.

The local wake-up scheduling (LWS) [12] is an ant colony based scheduling method to prolong the network lifetime with full coverage impulsion. In this method, the artificial ants search solutions in a two-phased manner. The first phase finds a set of sensors that satisfy full coverage constraint while the second phase finds the successors of sensors which run out of energy. In addition, graphs are designed to guide the artificial ants to search partial solutions in the two phases.

An Energy Efficient Adaptive Sensor Scheduling (EEASS) [13] accounts for target monitoring algorithm in WSNs. A motion monitoring algorithm is devised based on energy balance in local monitoring region of WSNs. An improved particle filter algorithm for degeneracy is applied to localize the target. Due to the redundant information collected from sensor nodes in the cluster, a sensor selection method is felt essential. The problem of sensor selection is exchanged into energy optimization subject to the decision function and the joint detection probability. Sensor nodes with higher decision values are selected under the condition of the joint detection probability and superior performances (i.e., tracking accuracy, residual energy of a sensor node, accumulated energy consumption, and lifetime of WSNs) for target tracking.

As indicated in [14], the scheduling algorithm introduced for Wireless Multimedia Sensor Networks (WMSNs) divides the frame sent from the cluster head to the base station into slots and gives a certain percentage of these slots to each node. These percentages are calculated taking into account the node priority and the strength of the flow from that node into the CH. The percentage is subjected to recalculation each time the CH receives a new query with new nodes involved. In WMSNs the multimedia streaming might cover eventually long periods of monitoring; the queries will be separated by certain periods of time and thus the recalculation does not impose a burden on the scheduler.

The Energy Efficient Routing Scheme for Sensor Networks Using Connected Dominating Set (CDS) [15] highlights a power aware routing approach with two phases. The first phase discusses the sparse topology over the visibility graph of the network in a localized manner. The second phase computes the data gathering tree over the edges of the computed sparse topology. The overall routing hierarchy inherits the flooding technique.

The survey concludes that most attention has been focused on the issues relevant to small sensor networks. However, the significance of the large scale WSNs in interaction with the outside world is not considered. Also the techniques addressed are found to be application specific. Therefore, cooperation among sensor networks creating groups of different sensor networks that accounts to a large scale WSN could be an area worth looking into.

3. Implementation of Proposed Scheme

An Energy Efficient Cluster based Scheduling Scheme (EECSS) that emphasizes enhancing network lifetime and curtail energy consumption using cluster based scheduling approach is recommended. Likewise, there are several related existing works highlighting the energy and lifetime parameters of individual sensor nodes. In contrast, our scheme enunciates the lifetime of cluster groups based on prioritised CH selection and total energy consumption of cluster nodes. In the proposed scheduling algorithm, time slots are assigned to CHs and cluster members. The sensor nodes are continuously monitored during listening, sleeping, and transmission phases. Moreover, the cluster topology is discovered to increase network lifetime and attain maximum residual energy across the entire network. In cluster model, the CH is being chosen for managing the connectivity of all the cluster member nodes.

3.1. High Energy Cluster Topology. In the proposed high energy cluster topology, network is organized as clusters, where each cluster member is associated with CH. Here, no base station is implemented. Cluster members and CHs communicate without any centralized infrastructure. Each cluster member node transmits the data via CH. The CH is chosen based on remaining energy level. The sensor nodes with maximum remaining energy levels are employed as CHs. The implementation of cluster topology relies on

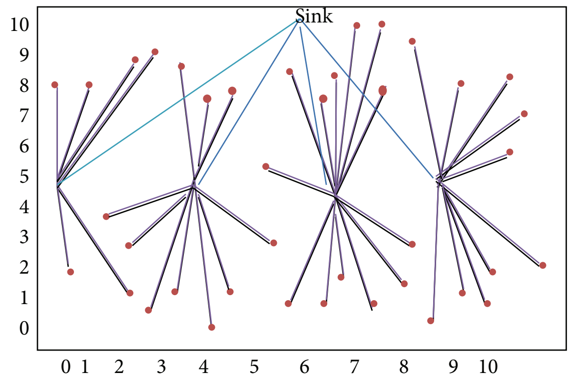

FIGURE 1: Cluster topology.

time slot based scheduling algorithm. In general, CHs are nodes that expose highest energy consumption due to their continuous data transmissions to remote base stations. Hence the probability for CHs to run out of energy is comparatively very high. To overcome this, the cluster topology employs new CHs based on the residual energy parameter. This paves the way for the energy consumption to be balanced across the entire network which in turn increases the network lifetime. In addition, there is a tradeoff between energy consumption and distance between CH and cluster members. With cluster topology, each cluster has at least one CH. Hence sensor networks that comprise multiple clusters have multiple CHs, which consume more energy. Our approach attempts to balance the energy consumption by allowing the sensor node with highest residual energy to act as CH at each round of communication. Hence the cluster topology proposed ensures maximum number of nodes with high residual energy as shown in Figure 1.

Cluster Topology Discovery Procedure for CH Selection. In a cluster group, each cluster member sensor node generates a random energy probability (E_t) at the beginning of a cluster discovery and computes the threshold value ($\tau(k)$) with the use of equation:

$$\tau(k) = \begin{cases} \dfrac{E_t}{1 - E_t\left(m \cdot \bmod\left(1/E_t\right)\right)} \cdot \dfrac{E_{\text{rem}}}{E_{\max}} & k \in N \\ 0 & \text{otherwise,} \end{cases} \quad (1)$$

where N is the set of cluster groups, E_{rem} is the remaining battery energy, $E_{\max}$ is the maximum battery energy of the sensor node, E_t is the desired percentage of CHs, and m is the current round number. In case of $E < E_t$, the node is selected as a CH.

A chosen CH broadcasts data packets to neighbouring cluster member nodes. The cluster member nodes collect the data messages for a given time interval and then send a "LINK-REQ" message to the closest CH. On receiving the "LINK-REQ" message the CH builds a cluster member routing table list and a time slot based schedule given by Time Division Multiple Access (TDMA). The time slots generated are broadcasted to the neighbouring cluster member nodes. The time slots convey the time instants for the cluster member nodes to send their data and energy information to their corresponding CHs. In turn the member nodes receiving the time slots restore the same for data transfers. Once cluster selection process is over, each cluster member sends data and its remaining energy information to the corresponding CH as per the given time slot schedule. Consecutively, the CH maintains remaining energy information of cluster member nodes.

In cluster topology presetup phase, a CH sends out the maximum residual energy value of all its cluster member nodes to another CH before last round of transmission expires. In this manner, each CH collects the remaining energy values from all CHs and attempts to find the maximum remaining energy value ($E_{\max}$) of the network. Ultimately, the $E_{\max}$ computed is communicated to all other CHs. The CH broadcasts Emax to cluster member sensor nodes. Each node saves the value of $E_{\max}$ for the subsequent computation of $\tau(k)$ and the current round is terminated.

3.2. Scheduling Algorithm. The scheduling algorithm proposed identifies the sensor nodes based on their active, idle, and sleep modes. The time ON and time OFF factors are calculated for nodes that are either in sleep or in active mode in order to allocate time slots to all cluster member nodes. The waiting time for cluster member sensor nodes is calculated based on their status of listening, sleeping, and activation stages. In addition, an assumption is made that the sensor nodes considered are mobile in nature and the clusters get reorganised as a function of time.

Step 1 (compute ON (t_{ON}) and OFF time (t_{OFF})). The t_{ON} represents the duration of time for which a sensor node is on:

$$t_{\text{ON}} = \frac{f - r}{v_{\max}}, \quad (2)$$

where $f - r$ is the minimum time for the sensor node to get into coverage and $V_{\max}$ is the maximum sensing range of the node.

The t_{OFF} represents the duration of time for which a sensor node is off:

$$t_{\text{OFF}} = \min\left\{\frac{f + r}{v_{\min}}, t_{\exp}\right\}, \quad (3)$$

where $f + r$ is the maximum time for the sensor node to get into coverage and $V_{\max}$ is the minimum sensing range of the node.

Step 2. Each cluster has its own identifier and each cluster member node is identified by a unique codeword within the cluster.

Step 3. Update current remaining energy E_{rems}.

Step 4. Collect information and construct the set of cluster groups.

Step 5. Compute the waiting time w_{ck} and start the decision phase timer t_{ON}. The waiting time for the cluster member sensor nodes is calculated based on their status of listening, sleeping, and activation:

$$w_{\mathrm{ck}} = \begin{cases} \dfrac{\eta}{k_i^{\chi} l(e_i, v_i)^{\alpha}} \times W + z & e_i \geq e_T \\ W & \text{otherwise}, \end{cases} \quad (4)$$

where η, χ, α are the constants, e_T is the threshold energy level, z is a random number between $[0 \cdot t_{\mathrm{ON}}]$, and $l(e_i, v_i)$ is the function computing the lifetime of cluster groups in terms of current energy e_i and its sensing range v_i.

Step 6. Status = LISTENING

Step 7. Precheck redundant neighbors, whether nodes are in sleep state. Send message to them and move them out of list L if found any.

Step 8. n_i = number of elements of list L

while $t \leq W$ do

Receive (CM_i, MessageID)

if MessageID == kACTIVATE (Activated message) then

Step 9. Update coverage level. Check if any sensor in list L is useless to CM_i's coverage.

If yes, kATSLEEP (Nodes are in sleep mode) send message to that sensor

else if MessageID == kATSLEEP then

if $n_i > 0$ and status == LISTENING then

Step 10. Update w_{ck}

if ($t \leq w_{\mathrm{ck}}$ and status == LISTENING) or $n_i == 0$ then

if $n_i == 0$ then

Set the timer Ri for si waking up at next round

else

status = ACTIVE

Set itself to be *Active*

Step 11. One-hop broadcast kACTIVATE message

3.3. Energy Consumption Model. The free space propagation model is utilised for modelling the energy consumption of a sensor node during transmission, reception, idle, and sensing states. The modelling takes into account the distance over which the sensor nodes communicate. Hence, the transmission energy of CH over a distance d is given as

$$\begin{aligned} E_{\mathrm{tx}}(n, d) &= E_{\text{tx-elec}}(n) + E_{\text{tx-amp}}(n, d) \\ &= \begin{cases} nE_{\mathrm{elec}} + n\xi_{\mathrm{fs}} d^2 & d < d_0 \\ nE_{\mathrm{elec}} + n\xi_{\mathrm{amp}} d^4 & d \geq d_0, \end{cases} \end{aligned} \quad (5)$$

Table 1: Proposed packet format.

Source Cluster ID	Destination Cluster ID	Scheduling status	Network lifetime	Total energy level	FCS
2	2	4	4	4	2

where E_{elec} is the transmitter circuitry dissipation per bit. Consider

$$E_{\mathrm{rx}}(n) = E_{\text{rx-elec}}(n) = nE_{\mathrm{elec}}. \quad (6)$$

Our main goal is to minimize the network cost in terms of energy, to prolong the lifetime. The mathematical model is given as $\mathrm{Min}(E_{\mathrm{tot}})$, that is, the minimum total energy expenditure:

$$E_{\mathrm{tot}} = E_t + E_r + E_i + E_s, \quad (7)$$

where E_{tot} is total energy expenditure across the network, E_t is the energy consumed during transmission, E_r is the energy consumed during reception, E_i is the energy spent when the nodes are in idle state, and E_s is the energy spent for sensing. In the energy consumption model, E_r, E_i, and E_s are constant and E_t varies based on the distance covered during transmission.

3.4. Proposed Packet Format. In Table 1 the parameters Source Cluster ID and Destination Cluster ID uniquely identify the Source and Destination clusters for a particular round of communication. Scheduling Status indicates the status of the node to be either active, sleep, or listening. Network lifetime indicates how long a sensor node lives with optimum remaining energy level within the current cluster. Total Energy Level is the overall energy of the cluster group which is monitored by all CHs. Frame Check Sequence (FCS) is to identify duplications across the frames transmitted.

Figure 2 represents the workflow of the proposed system. Initially, the cluster topology discovery phase is primly set out to organise the WSN as a clustered sensor network. Here the sensor nodes are configured as member nodes of a cluster only based on their residual energy levels. Then, with the integration of the energy consumption model, the energy spent during various network tasks is estimated. Finally, the time slot based scheduling is performed in the basis of Time Division Multiple Access. The set of sensor nodes that are schedulable for a particular round of communication are identified.

4. Simulation

In this section, we demonstrate that the derived results above are consistent with simulation results. We use NS2.34 to conduct a performance study to compare the performance of EECSS with that of HEF and investigate the feasibility of EECSS. There are 200 sensor nodes, organized in a random topology and randomly deployed in a square region 1200 * 1200 meters in size. The simulation is prone to a maximum of 60 seconds. The entire sensor nodes are considered to have a transmission range of 500 meters. The simulation parameters are listed in Table 2.

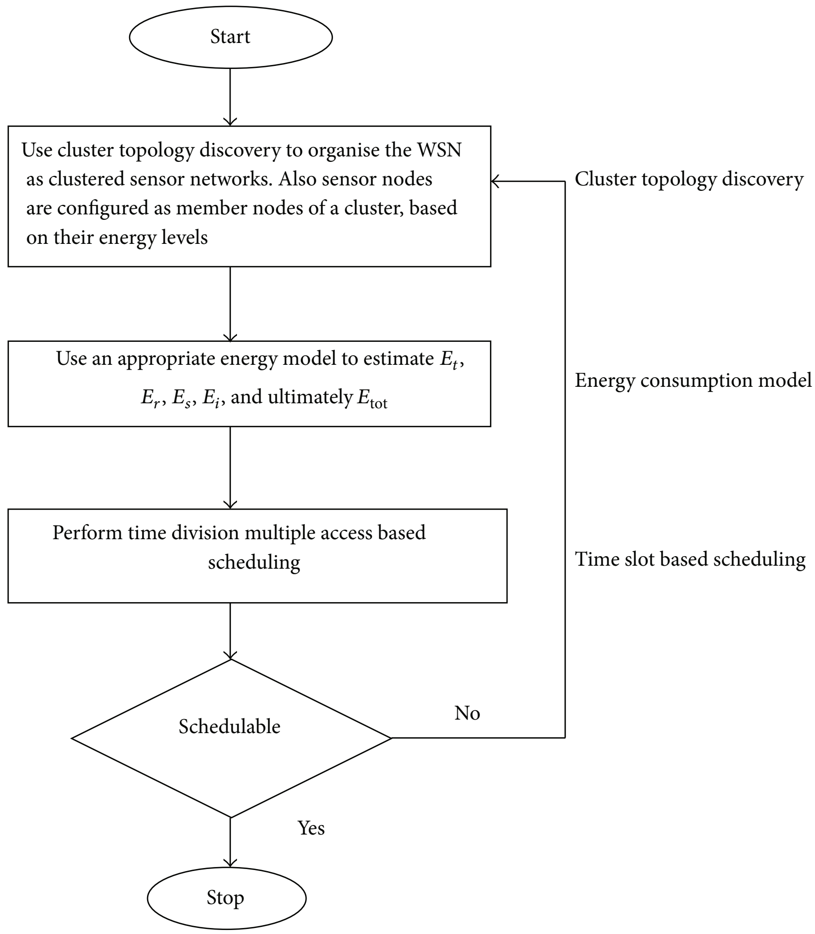

Figure 2: Flowchart of proposed scheme.

Table 2: Simulation parameters.

Parameters	Value
Number of nodes	200
Network size	1200 × 1200
Mac	802.11
Radio range	500 m
Simulation time	60 sec
Traffic source	Constant bit rate (CBR)
Packet size	512 bytes
Mobility model	Random way point

4.1. Performance Metrics. We evaluate the performance of the work proposed in terms of the following.

End-to-End Delay. The simulation averages the time taken for all surviving data packets to be transmitted across the network from sources to destinations.

Packet Delivery Ratio. It represents the ratio of packets that are successfully delivered to a destination compared to the number of packets that have been sent out by the sender. The simulation in turn generalises this successful delivery ratio across entire sources and destinations identified in the network.

Throughput. In terms of throughput the simulation attempts to average the overall rate of successful message delivery across all communication channels or communication links present in the network.

Communication Overhead. The total number of control packets that convey control information is normalised by the total number of actual data packets and hence a least communication overhead is experienced during the simulation.

Energy Consumption. The EECSS relates energy consumption to different states (transmit, receive, idle, and sense) of sensor nodes. With the high energy cluster topology, the simulation leads to uniform distribution of energy consumptionacross the network.

Network Lifetime. With higher emphasis on the efficient use of the critical network resources such as battery power, the EECSS prolongs the network lifetime in terms of energy retained in the individual sensor nodes and across clusters. The energy consumption model integrated allows our simulation to achieve maximum sensor nodes with optimal residual energy.

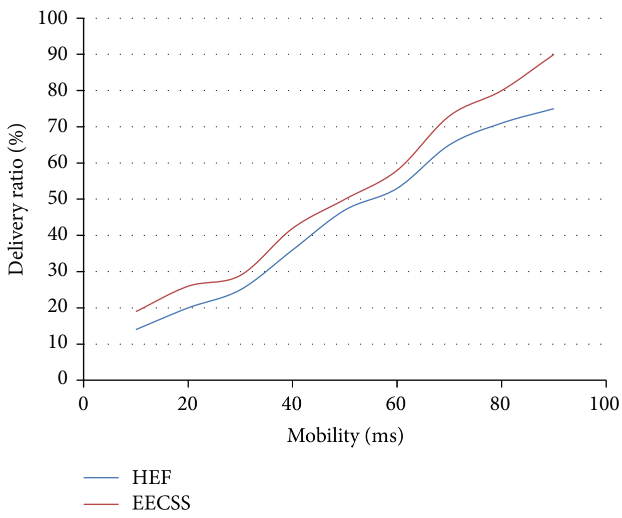

Figure 3: Number of nodes versus delivery ratio.

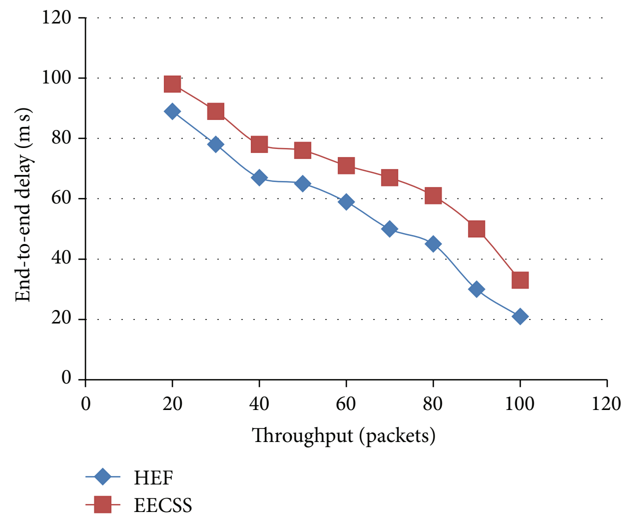

Figure 5: Throughput versus end to end delay.

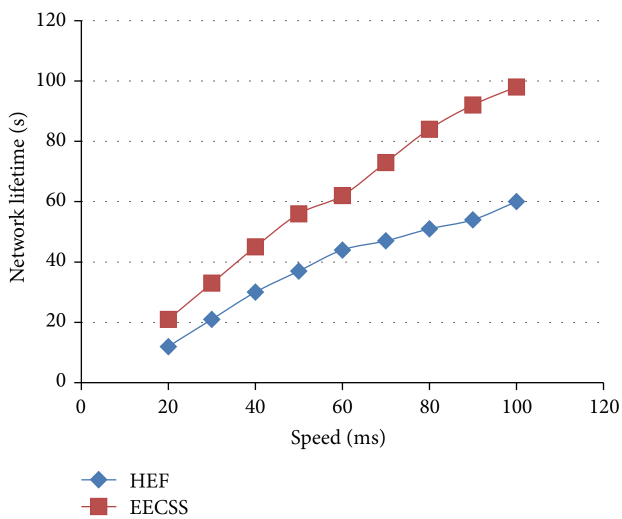

Figure 4: Speed versus network lifetime.

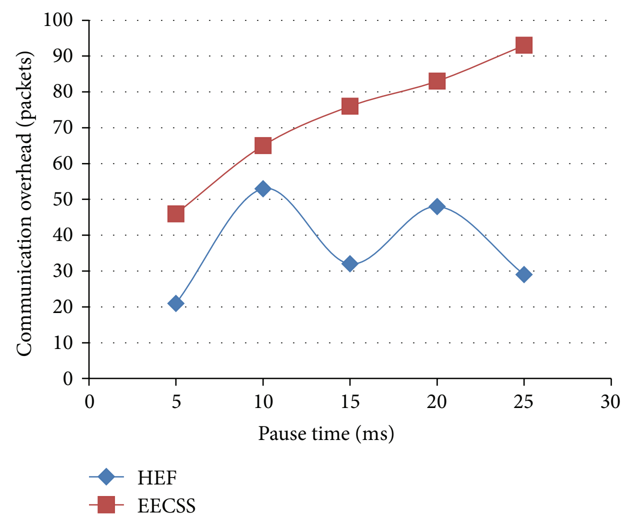

Figure 6: Pause time versus communication overhead.

The simulation results are presented. Also a comparative analysis that proves our proposed EECSS to outperform one among the relevant existing High Energy First Clustering (HEF) algorithm [9] is discussed in the following sections.

The experimentations discussed in the following section demonstrate EECSS to surpass HEF by taking into account network lifetime when energy consumption is balanced across the network.

The comparison results between EECSS and HEF in terms of delivery ratio are presented in Figure 3, where the Y-axis represents the delivery ratio and the X-axis denotes the mobility. The delivery ratio is varied in terms of mobility. With EECSS an increase in the mobility of sensor nodes leads to a phenomenal increase in successful delivery ratio and it proves to be better than HEF. Also our simulation generalises this successful delivery ratio across all the sources and destinations identified within the network and proves that maximum number of packets are delivered at destinations.

In Figure 4 the X-axis refers to the speed of the mobile sensor nodes and the Y-axis refers to the corresponding network lifetime. By varying the speed from 20 ms to 100 ms, EECSS proves to be better than HEF in terms of network lifetime because of its cluster topology and time based scheduling.

The performance of EECSS in contrast to HEF in terms of end-to-end delay and Network Throughput is presented in Figure 5. The Y-axis represents the end-to-end delay and the X-axis represents the Network Throughput. The proposed EECSS shows a decrease in delay when throughput increases. Also it outperforms HEF in terms of latency. It shows a minimal end-to-end delay even when the sum of data traffic to the destinations is large. Hence EECSS is found to be suitable for large scale WSNs.

In Figure 6 the X-axis refers to the pause time and the Y-axis represents the communication overhead. The simulation allows nodes to stop for a duration defined by the "*pause*

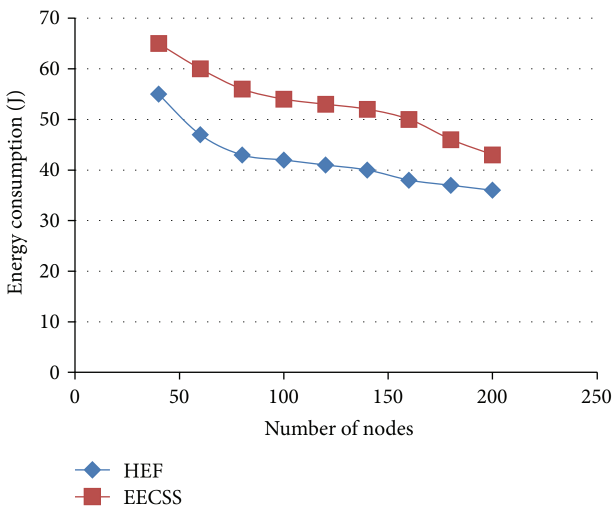

Figure 7: Number of nodes versus energy consumption.

time," after which it again chooses a random destination and repeats the whole process. With EECSS the total number of packets carrying actual data outplays the total number of packets carrying control information. Hence EECSS shows a phenomenal decrease in communication overhead compared to HEF.

The comparison results between EECSS and HEF in terms of energy consumption are presented in Figure 7, where the Y-axis represents the energy consumption and the X-axis denotes the number of nodes in the network. In EECSS, even if the network is scaled to a larger scale network supporting N number of nodes, energy consumption across the network decreases as the total number of network nodes increases. This is definitely achieved by the integration of high energy cluster topology and time based scheduling. The total energy consumption is balanced across the entire network which is not achieved in HEF.

5. Conclusion

In general, clustering in WSNs has been of high interest across research and industrial communities in the last decade. Throughout this work we have concentrated on the main characteristics of sensor networks such as network lifetime and energy consumption. As it was pointed out, EECSS paves way for grouping nodes into clusters, thus leading to energy efficient routing and scheduling has been proved as one among the most efficient approaches to support scalability in WSNs. Since it greatly reduces the total amount of communications as well as the energy spent, independent of the growth of WSN, it becomes highly suitable for real-time large scale WSNs. In contrast to the existing protocols that are in focus only towards the efficient utilization of critical battery resources which counts for the lifetime of the sensor nodes and ultimately lifetime of the sensor networks, our proposed work combines the need for fast convergence time and minimum energy consumption with regard to the cluster formation procedure. Moreover, nodes are assumed to make fast decisions, that is, to become CHs or not, based on their residual energies and not based on any random probabilities. The most critical feature of EECSS is the periodic reelection of CHs, based on residual energies among all the nodes of the network leading to uniform distribution of energy consumption. Habitually, it introduces a multi-level cluster hierarchy to preserve energy efficiency independent of the growth of the network in terms of number of sensors, area covered, and so forth, and it well suits real-time large scale WSNs. Finally, a few additional issues should be explored in future research. Some of these issues include the evolution of a comprehensive method for finding the optimal number of clusters in order to maximize the energy efficiency, the estimation of the optimal frequency of CH rotation/reelection to gain better energy distribution, the incorporation of several security aspects to enhance protection in hostile environments, and the further development of recovery protocols in case of CHs failure.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Multicriteria Personnel Selection by the Modified Fuzzy VIKOR Method

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Personnel evaluation is an important process in human resource management. The multicriteria nature and the presence of both qualitative and quantitative factors make it considerably more complex. In this study, a fuzzy hybrid multicriteria decision-making (MCDM) model is proposed to personnel evaluation. This model solves personnel evaluation problem in a fuzzy environment where both criteria and weights could be fuzzy sets. The triangular fuzzy numbers are used to evaluate the suitability of personnel and the approximate reasoning of linguistic values. For evaluation, we have selected five information culture criteria. The weights of the criteria were calculated using worst-case method. After that, modified fuzzy VIKOR is proposed to rank the alternatives. The outcome of this research is ranking and selecting best alternative with the help of fuzzy VIKOR and modified fuzzy VIKOR techniques. A comparative analysis of results by fuzzy VIKOR and modified fuzzy VIKOR methods is presented. Experiments showed that the proposed modified fuzzy VIKOR method has some advantages over fuzzy VIKOR method. Firstly, from a computational complexity point of view, the presented model is effective. Secondly, compared to fuzzy VIKOR method, it has high acceptable advantage compared to fuzzy VIKOR method.

1. Introduction

Personnel evaluation is a complex process in the scope of which many factors should be evaluated simultaneously in a decision-making process. Evaluation process should provide reliable and valid information about alternatives. There are some conventional techniques used in this process: mainly, completion of application forms, initial interview, employment test, and background investigation. The conventional personnel evaluation techniques that are developed on the basis of static job characteristics will no longer suffice. These methods generally come to a conclusion on the basis of the subjective judgment of decision-maker, which makes the accuracy of the results highly questionable. Moreover, these methods take into consideration some classical criteria (age, experience, etc.) in the decision-making process [1, 2]. Various studies have been conducted on personnel evaluation problem to eliminate the drawbacks of conventional personnel evaluation techniques [3–7]. Chien and Chen [3] reviewed the personnel evaluation studies and found that the important issues including change in organizations, change in work, change in personnel, change in the society, change of laws, and change in marketing have influenced personnel evaluation and recruiting. Personnel recruitment and evaluation directly affect the quality of employees [3]. Hence, various new technologies, like computer-based testing, internet-based testing, telephone-based interviews, video-conference job interviews, and multimedia simulation tests, allow organizations to test large numbers of applicants at the same time and help in saving time and money and make better personnel evaluation decisions [8].

Recent studies stated that an information culture plays an important role in the success of the modern organizations [9–14]. Information culture is an important factor that must be stimulated in all types of modern organization management. Khan and Azmi [15] explained that information culture is a culture where information is the essence of all activities in organization. Choo et al. [16] and Bergeron et al. [17] looked at information culture as the socially shared patterns of behaviors, norms, and values that define the significance and use of information in an organization. To profile an organization's information culture, in more recent studies, Choo et al. [18] adapted six criteria: (1) *information integrity*, (2) *information formality*, (3) *information control*, (4) *information transparency*, (5) *information sharing*, and (6) *information proactiveness*. Choo [9] presented four information culture types as follows: result-oriented: it pursues goal achievement and competitive advantage; rule-following: it pursues control, compliance, and accountability; relationship-based: it encourages communication, participation, and commitment; risk-taking: it encourages innovation, creativity, and exploration of new ideas. Each information culture type may be characterized by a set of 5 attributes: the primary goal of information management, information values and norms, information behaviors in terms of information needs, information seeking, and information use. Authors of [19] state that information culture of personnel may be characterized by a set of five criteria, namely, (1) *information gathering and perception skill*; (2) *information memorization skill*; (3) *information handling skill*; (4) *information protection and security skill*; and (5) *information presentation skill*. So, in this study, for personnel evaluation, we will use these criteria which will be explained in Section 4.

It is known that selecting the best alternative among many alternatives is a multicriteria decision-making (MCDM) problem. MCDM is one of the most widely used decision methodologies in science, business, and engineering worlds. MCDM methods aim at improving the quality of decisions by making the process more explicit, rational, and efficient [20, 21]. A typical MCDM problem involves a number of alternatives to be evaluated and a number of criteria to evaluate the alternatives. MCDM methods deal with problems of compromise evaluation of the best solutions from the set of available alternatives according to objectives.

In this paper, an integrated fuzzy MCDM approach was proposed for the information personnel evaluation process. The objective of this study is to determine the evaluation criteria and to evaluate personnel by means of modified VIKOR [22] under a fuzzy environment. In this study, the "worst-case" method [23] is used to determine the relative weight of the criteria and the modified fuzzy VIKOR method is proposed to rank the alternatives in terms of overall performance with respect to multiple information culture criteria.

This paper is organized as follows. In Section 2, we first introduce the literature review on MCDM in personnel evaluation. Section 3 describes basic concepts of fuzzy sets and fuzzy numbers. In Section 4, a modified fuzzy VIKOR method is presented and its steps are determined in detail. Section 5 describes worst-case method, which is used to determine weights of the evaluation criteria. How the proposed model is used on a real world example is explained in Section 6. Finally, we conclude this paper in Section 7.

2. Literature Review on MCDM in Personnel Evaluation

Among the MCDM problems that we encounter in real life is the personnel evaluation problem. The personnel evaluation problem, from the multicriteria perspective, has attracted the interest of many researchers. In the literature, there are a number of studies that have been conducted on personnel evaluation. The world around us is difficult to see in one-dimensional way in order to assess what we see. So we always compare and rank objects of our choice with respect to different criteria. In this context MCDM is a powerful tool widely used in evaluating, selecting, or ranking a finite set of decision alternatives characterized by multiple and usually conflicting criteria [24–26]. It can help users understand the results of integrated assessments. At present, different researchers have proposed many MCDM methods: AHP (Analytic Hierarchy Process) [27, 28], TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [29], VIKOR (VIsekriterijumska Optimizacija i KOmpromisno Resenje: multicriteria optimization and compromise solution) [22], ELECTRE II (ELimination Et Choix Traduisant la REalité: ELimination and Choice Translating REality) [30], PROMETHEE II (Preference Ranking Organization METHod for Enrichment Evaluation) [31], and DEA (Data Envelopment Analysis) [32]. Due to vagueness in the data and ambiguity in decision-making process, fuzzy set theory has been incorporated into MCDM techniques by many researchers for personnel selection problem. Among these techniques, TOPSIS and VIKOR methods seemed to be more appropriate for solving the personnel selection problem because they have capability to deal with each kind of judgment criteria, having clarity of results and easiness to deal with attributes and decision options [33].

TOPSIS was proposed by Hwang and Yoon [29] to determine the best alternative based on the concepts of the compromise solution. The main concept of the TOPSIS method is that the chosen alternative should have the shortest Euclidean distance from the positive-ideal solution and the farthest Euclidean distance from the negative-ideal solution. Positive-ideal solution is the one that maximizes the benefit criteria and minimizes the cost criteria, while the negative-ideal solution maximizes the cost criteria and minimizes the benefit criteria. This method defines an index called closeness to positive-ideal solution and the farthest from the negative-ideal solution. Finally, this method chooses an alternative with the maximum closeness to the positive-ideal solution. The compromise solution can be regarded as choosing the solution with the shortest Euclidean distance from the ideal solution and the farthest Euclidean distance from the negative-ideal solution [33–36].

The AHP method requires pairwise comparison of various alternatives with respect to each of the criteria and pairwise comparison criteria themselves. When the number of alternatives and/or criteria increases then the size and number of the comparison matrices increase. The improved AHP method by eliminating the comparison matrices required for alternatives was suggested by Rao [36]. In the improved AHP method, by normalizing the values of criteria by a systematic way, the rank reversal problem also is removed. To avoid the laborious procedures of generating and processing paired comparison matrices, Rotshtein [23] proposes worst-case method. This method instead of pairwise comparison uses special relations based on comparison with the worst alternative and with the least important criterion.

The highest ranked alternative by TOPSIS is the best in terms of the ranking index, which does not mean that it is always closest to the positive-ideal solution. Hence a new approach based on fuzzy VIKOR method is also used to obtain the rankings. This method focuses on ranking and selecting from a set of alternatives and determines compromise solutions for a problem with conflicting criteria [33]. VIKOR is a helpful tool in MCDM, particularly in a situation where the decision-maker is not able or does not know how to express preference in the beginning of system design. VIKOR ranks alternatives and determines the solution named compromise that is the closest to the ideal. Su [37] proposed a hybrid fuzzy approach, which assesses each alternative in terms of distance measure calculated by a modified VIKOR method.

The AHP method has been criticized as decision problems are structured in a hierarchical manner. Some decision-making problems cannot be structured hierarchically because they involve the interaction and dependence of higher level elements on lower elements. To solve the problem of dependence among alternatives and criteria, Saaty [28] proposed the use of analytic network process (ANP). The ANP was proposed to extend the AHP to release the restrictions of the hierarchical structure, which indicates that the criteria are independent from each other.

AHP can effectively handle both qualitative and quantitative data, but the conventional AHP still cannot reflect the ambiguity in human thinking style. Therefore, to solve these problems, some solutions to fuzzy MCDM problems were proposed, such as fuzzy AHP and fuzzy TOPSIS. They are the key tools used to solve the evaluation and scheduling problems under the fuzzy multicriteria conditions [38]. Güngör et al. [39] have developed a personnel evaluation system based on fuzzy AHP. Dursun and Karsak [6] presented a fuzzy MCDM algorithm using the principles of fusion of fuzzy information, 2-tuple linguistic representation model, and TOPSIS. Lately, Zhang and Liu [5] and Guo [40] used grey relational analysis to solve the personnel evaluation problem under an intuitionistic fuzzy environment. In [3], a data mining framework for personnel evaluation to explore the association rules between personnel characteristics and work behaviors has been developed, including work performance and retention.

Numerous fuzzy MCDM methods have been developed and there is no best method for the general fuzzy MCDM problem. Most fuzzy number ranking methods suffer from various drawbacks such as (a) lack of sensitivity when comparing similar fuzzy numbers, (b) counterintuitive outcomes in certain circumstances, and (c) complex computational processes [20, 41]. Therefore, in recent years, researchers have attempted to combine different methods to select the best alternative. For supporting the personnel evaluation process in the manufacturing systems, Dağdeviren [2] proposed a hybrid model which employs ANP and modified TOPSIS. Lin [32] combined ANP with fuzzy data envelopment analysis and proposed an integrated method to solve the personnel evaluation problem. For solving a personnel evaluation problem Baležentis et al. [42] proposed the new hybrid MULTIMOORA-FG method to cope with group decision making by employing fuzzy weighted averaging operator. Further, in [43], the MULTIMOORA method was extended by employing type-2 fuzzy sets with generalized interval-valued trapezoidal fuzzy numbers. The new fuzzy MULTIMOORA method, as in the case of the crisp MULTIMOORA, consists of three parts, namely, the Ratio System, the Reference Point, and the Full Multiplicative Form, representing different approaches of data aggregation.

3. Basic Concepts of Fuzzy Sets and Fuzzy Numbers

Fuzzy set theory, introduced by Zadeh [44], deals with problems in which a source of vagueness is involved and has been utilized for incorporating imprecise data into the decision framework.

A tilde "~" will be placed above a symbol if the symbol represents a fuzzy set.

Definition 1 (fuzzy set). Let U be the universe of discourse, $U = \{u_1, \ldots, u_n\}$. A fuzzy set $\widetilde{A}$ of U is a set of order pairs $\{(u_1, \mu_{\widetilde{A}}(u_1)), \ldots, (u_n, \mu_{\widetilde{A}}(u_n))\}$, where $\mu_{\widetilde{A}} : U \rightarrow [0,1]$ is the membership function of $\widetilde{A}$ and $\mu_{\widetilde{A}}(u_i)$ stands for the membership degree of u_i in $\widetilde{A}$.

A fuzzy number is an extension of a regular number in the sense that it does not refer to one single value but rather to a connected set of possible values, where each possible value has its own weight between 0 and 1. This weight is called the membership function. In fact the use of triangular fuzzy numbers (TFNs) is easy and understandable for decision-makers. In this paper we also tool for the use them as a proper for the study.

Definition 2 (fuzzy number). A TFN denoted by $\widetilde{A}$ is defined as follows: $\widetilde{A} = (a^l, a^m, a^u)$, where $a^l \leq a^m \leq a^u$. a^l denotes the smallest possible value, while a^m is the most promising value, and a^u is the largest possible value. Each TFN has linear representations on its left and right side such that its function can be defined as

$$\mu_{\widetilde{A}}(x) = \begin{cases} 0, & x < a^l \text{ or } x > a^u, \\ \dfrac{x - a^l}{a^m - a^l}, & a^l \leq x \leq a^m, \\ \dfrac{a^u - x}{a^u - a^m}, & a^m \leq x \leq a^u. \end{cases} \quad (1)$$

$\mu_{\widetilde{A}}(a^m) = 1$ for a^m to be on the top of the triangular fuzzy number.

Mathematical operations on TFNs are defined as follows.

Definition 3 (operations). The following arithmetic operations can be performed on TFNs. Let $\widetilde{A} = (a^l, a^m, a^u)$ and $\widetilde{B} = (b^l, b^m, b^u)$ be two TFNs. Then fuzzy arithmetic operations are defined as follows.

(i) Summation. One has $\widetilde{A}+\widetilde{B}=(a^l+b^l, a^m+b^m, a^u+b^u)$.

Example 1. Let $\widetilde{A}=(2,5,7)$ and $\widetilde{B}=(3,4,6)$ be two TFNs. Then

$$\widetilde{A}+\widetilde{B}=(2+3,5+4,7+6)=(5,9,13). \tag{2}$$

(ii) Subtraction. One has $\widetilde{A}-\widetilde{B}=(a^l-b^u, a^m-b^m, a^u-b^l)$.

Example 2. Let $\widetilde{A}=(2,5,7)$ and $\widetilde{B}=(3,4,6)$ be two TFNs. Then

$$\begin{aligned}\widetilde{A}-\widetilde{B}&=(2,5,7)-(3,4,6)=(2-6,5-4,7-3)\\&=(-4,1,4).\end{aligned} \tag{3}$$

(iii) Multiplication. Scalar multiplication of TFN by a real number is as follows:

$$r\widetilde{A}=\begin{cases}\left(ra^l, ra^m, ra^u\right), & \text{if } r\ge 0,\\ \left(ra^u, ra^m, ra^l\right), & \text{if } r<0,\end{cases} \tag{4}$$

where r denotes a real number.

Example 3. Let $\widetilde{A}=(-2,4,9)$ be a TFN and $r=3$. Then

$$\begin{aligned}r\times\widetilde{A}&=3\times(-2,4,9)=(3\times(-2),3\times 4,3\times 9)\\&=(-6,12,27).\end{aligned} \tag{5}$$

Example 4. Let $\widetilde{A}=(-2,4,9)$ be a TFN and $r=-3$. Then

$$\begin{aligned}r\times\widetilde{A}&=(-3)\times(-2,4,9)\\&=((-3)\times 9,(-3)\times 4,(-3)\times(-2))\\&=(-27,-12,6).\end{aligned} \tag{6}$$

Multiplication of two TFNs is as follows:

$$\begin{aligned}\widetilde{A}\times\widetilde{B}=&\left(\min\left\{a^l\times b^l, a^l\times b^u, a^u\times b^l, a^u\times b^u\right\}, a^m\right.\\&\left.\times b^m, \max\left\{a^l\times b^l, a^l\times b^u, a^u\times b^l, a^u\times b^u\right\}\right).\end{aligned} \tag{7}$$

Example 5. Let $\widetilde{A}=(2,5,7)$ and $\widetilde{B}=(3,4,6)$ be two TFNs. Then

$$\begin{aligned}\widetilde{A}\times\widetilde{B}=&(\min(2\times 3,2\times 6,7\times 3,7\times 6),5\\&\times 4,\max(2\times 3,2\times 6,7\times 3,7\times 6))=(6,20,42).\end{aligned} \tag{8}$$

(iv) Division. Consider

$$\begin{aligned}\widetilde{A}\div\widetilde{B}=&\left(\min\left\{a^l\div b^l, a^l\div b^u, a^u\div b^l, a^u\div b^u\right\}, a^m\right.\\&\left.\div b^m, \max\left\{a^l\div b^l, a^l\div b^u, a^u\div b^l, a^u\div b^u\right\}\right).\end{aligned} \tag{9}$$

Example 6. Let $\widetilde{A}=(2,5,7)$ and $\widetilde{B}=(3,4,6)$ be two TFNs. Then

$$\begin{aligned}\widetilde{A}\div\widetilde{B}&=\left(\min\left(\frac{2}{3},\frac{2}{6},\frac{7}{3},\frac{7}{6}\right),\frac{5}{4},\max\left(\frac{2}{3},\frac{2}{6},\frac{7}{3},\frac{7}{6}\right)\right)\\&=\left(\frac{2}{6},\frac{5}{4},\frac{7}{3}\right)=\left(\frac{1}{3},\frac{5}{4},\frac{7}{3}\right).\end{aligned} \tag{10}$$

(v) The Fuzzy Inverse. One has

$$\left(\widetilde{A}\right)^{-1}=\left(\frac{1}{a^u},\frac{1}{a^m},\frac{1}{a^l}\right). \tag{11}$$

Example 7. Let $\widetilde{A}=(2,5,7)$; then $(\widetilde{A})^{-1}=(1/7,1/5,1/2)$.

(vi) Max and Min. Consider

$$\begin{aligned}&\max\left(\widetilde{A},\widetilde{B}\right)\\&\quad=\left(\max\left(a^l,b^l\right),\max\left(a^m,b^m\right),\max\left(a^u,b^u\right)\right),\\&\min\left(\widetilde{A},\widetilde{B}\right)\\&\quad=\left(\min\left(a^l,b^l\right),\min\left(a^m,b^m\right),\min\left(a^u,b^u\right)\right).\end{aligned} \tag{12}$$

Example 8. Let $\widetilde{A}=(2,5,7)$ and $\widetilde{B}=(3,4,6)$ be two TFNs. Then

$$\begin{aligned}\max\left(\widetilde{A},\widetilde{B}\right)&=(\max(2,3),\max(5,4),\max(7,6))\\&=(3,5,7),\\ \min\left(\widetilde{A},\widetilde{B}\right)&=(\min(2,3),\min(5,4),\min(7,6))\\&=(2,4,6).\end{aligned} \tag{13}$$

(vii) The Absolute Value. The absolute value of the TFN $\widetilde{A}=(a^l, a^m, a^u)$ is denoted by $|\widetilde{A}|$ and defined as follows [45–47]:

$$\left|\widetilde{A}\right|(x)=\begin{cases}\max\left\{\widetilde{A}(x),-\widetilde{A}(-x)\right\}, & \text{if } x\ge 0,\\ 0, & \text{if } x<0.\end{cases} \tag{14}$$

Example 9. Let us consider $\widetilde{A}=(4,7,11)$. Since $a^l=4>0$, then

$$\left|\widetilde{A}\right|=\widetilde{A}=(4,7,11). \tag{15}$$

Example 10. Let us consider $\widetilde{A}=(-8,-5,-1)$, so $-\widetilde{A}=(1,5,8)$. Since $a^u=-1<0$, then

$$\left|\widetilde{A}\right|=-\widetilde{A}=(1,5,8). \tag{16}$$

Example 11. Let $\widetilde{A} = (-2, 4, 6)$, so $-\widetilde{A} = (-6, -4, 2)$. Since $0 \in [a^l, a^u] = [-2, 6]$, then

$$\left|\widetilde{A}\right| = (0, 4, 6). \tag{17}$$

Example 12. Let us consider $\widetilde{A} = (-8, 3, 6)$, so $-\widetilde{A} = (-6, -3, 8)$. Since $0 \in [a^l, a^u] = [-8, 6]$, then

$$\left|\widetilde{A}\right| = (0, 3, 8). \tag{18}$$

Definition 4 (distance). Let $\widetilde{A} = (a^l, a^m, a^u)$ and $\widetilde{B} = (b^l, b^m, b^u)$ be two TFNs. The distance between fuzzy numbers $\widetilde{A}$ and $\widetilde{B}$ is calculated as

$$d\left(\widetilde{A}, \widetilde{B}\right) = \sqrt{\frac{1}{3}\left[\left(a^l - b^l\right)^2 + \left(a^m - b^m\right)^2 + \left(a^u - b^u\right)^2\right]}. \tag{19}$$

Example 13. Let $\widetilde{A} = (-1, 5, 10)$ and $\widetilde{B} = (3, 8, 14)$ be two TFNs. Then

$$\begin{aligned} d\left(\widetilde{A}, \widetilde{B}\right) &= \sqrt{\frac{1}{3}\left[(-1-3)^2 + (5-8)^2 + (10-14)^2\right]} \\ &= \sqrt{\frac{1}{3}\left[16 + 9 + 16\right]} = \sqrt{\frac{41}{3}} \approx 3.7. \end{aligned} \tag{20}$$

Definition 5 (aggregation). Assume that a decision group has K decision-makers DM_k $(k = 1, 2, \ldots, K)$ and the fuzzy rating of each decision-maker can be represented as a positive TFN $\widetilde{A}_k = (a_k^l, a_k^m, a_k^u)$ with membership function $\mu_{\widetilde{A}_k}(x)$. Then the aggregated fuzzy rating $\widetilde{A} = (a^l, a^m, a^u)$ can be defined as follows:

$$\begin{aligned} a^l &= \frac{1}{K}\sum_{k=1}^{K} a_k^l, \\ a^m &= \frac{1}{K}\sum_{k=1}^{K} a_k^m, \\ a^u &= \frac{1}{K}\sum_{k=1}^{K} a_k^u. \end{aligned} \tag{21}$$

Example 14. Let $\widetilde{A}_1 = (-2, 4, 11)$, $\widetilde{A}_2 = (-3, 2, 7)$, $\widetilde{A}_3 = (2, 6, 9)$, and $\widetilde{A}_4 = (4, 6, 8)$ be four TFNs. Then the aggregated fuzzy rating $\widetilde{A} = (a^l, a^m, a^u)$ is

$$\begin{aligned} a^l &= \frac{(-2 - 3 + 2 + 4)}{4} = 0.25; \\ a^m &= \frac{(4 + 2 + 6 + 6)}{4} = 4.5; \\ a^u &= \frac{(11 + 7 + 9 + 8)}{4} = 8.75. \end{aligned} \tag{22}$$

So $\widetilde{A} = (0.25, 4.5, 8.75)$.

Definition 6 (defuzzification). The defuzzification value of $\widetilde{A}$ is an approximated real number. Various defuzzification strategies are suggested, while centroid method (often called center of area) is the most prevalent and physically appealing of all the defuzzification methods [48, 49]. In this study the fuzzy numbers are defuzzified using centroid method. For the triangular fuzzy numbers, $\widetilde{A} = (a^l, a^m, a^u)$, the defuzzified value is

$$A = \frac{\left(a^l + a^m + a^u\right)}{3}. \tag{23}$$

Example 15. Let us consider $\widetilde{A} = (-3, 2, 11)$. Then the defuzzification value of $\widetilde{A}$ is $A = (-3 + 2 + 11)/3 = 3.33$.

4. The Modified Fuzzy VIKOR Method

The VIKOR method was developed for multicriteria optimization of complex systems. This method focuses on ranking and selecting from a set of alternatives and determines compromise solutions for a problem with conflicting criteria, which can help the decision-makers to reach a final decision [50–52]. This method determines the compromise solution and is able to establish the stability of decision performance by replacing the compromise solution obtained with initial weights [53]. An extension of VIKOR to determine fuzzy compromise solution for multicriteria is presented in [54]. The fuzzy VIKOR method has been developed to solve problem in a fuzzy environment where both criteria and weights could be fuzzy sets [52]. In this study, the TFNs are used to handle imprecise numerical quantities. Fuzzy VIKOR is based on the aggregating fuzzy merit that represents distance of an alternative to the ideal solution. The fuzzy operations and procedures for ranking fuzzy numbers are used in developing the fuzzy VIKOR algorithm.

In VIKOR, each alternative is measured based on an aggregate function, so the compromise ranking of alternatives is implemented by comparing the measure of closeness to the ideal solution. One of the characteristics of VIKOR is that always aggregate function is closest to the best solutions, while in TOPSIS the closeness indices of alternatives necessarily are not always very close to the ideal values. The fuzzy VIKOR procedure consists of the following steps [22, 53–55].

Step 1 (identification of necessary criteria for personnel evaluation). In this step, the criteria that will be used to evaluate personnel are described briefly. Compared with the previous studies, the criteria for evaluating personnel are identified through literature review and investigation. The criteria that will be used to evaluate personnel are briefly explained as follows.

Culture of Gathering and Perception of Information (C_1). Information gathering is not limited to passive gather of only provided information by a person. It is a process that starts with comprehension of information demand necessary for solving any problem and combines skills such as information processing on existing information resources and

Table 1: Scale of the relative importance of criteria.

Intensity of importance, R_j/R_q	The relative importance of the criteria C_j and C_q	Explanation
1	Equal importance	The criterion C_j is equally important as the criterion C_q
2	Weak importance	Intermediate between 1 and 3
3	Moderate importance	The criterion C_j is moderately more important than the criterion C_q
4	Moderate more importance	Intermediate between 3 and 5
5	Strong importance	The criterion C_j is strongly more important than the criterion C_q
6	Strong more importance	Intermediate between 5 and 7
7	Very strong importance	The criterion C_j is very strongly more important than the criterion C_q
8	Very strong more importance	Intermediate between 7 and 9
9	Extreme importance	The criterion C_j is extremely more important than the criterion C_q

their structure, knowledge of information search algorithms in different information sources, determination of list of terms and key words in subjects, use of traditional and electronic information retrieval engines, and comprehension of obtained information regardless of presentation form and its types (text, audio, video, scheme, graph, etc.).

Culture Memorization of Information (C_2). Information memorization is one of the important components of information culture of an individual. Memorization process is connected to characteristics such as human memory and attention. Memory has a significant role and importance for succeeding in life. According to scientists, memory is the ability of a person to store obtained knowledge and experience and use them during his/her life and activities.

Culture Handling of Information (C_3). New skills are required from people in the period of rapid changes, occurring in society, and fast growth of information knowledge. A person must be able to analyze, evaluate information related to his activity, and create new information. Otherwise, it will be difficult to use obtained information and knowledge during the decision-making process regarding a certain issue. As along with abundance of information, availability of needless, uncertain information causes confusion. Thus, ability to evaluate, select, and analyze information is significant for professional activity of person.

Culture Protection and Security of Information (C_4). New value of information and its conversion into strategic resource brings its protection and provision of its safety to the foreground in modern period. Solving the information security problem depends on not only technical methods and devices, but also culture of people. Currently, ability to implement the processes of collection, storage, processing, and transfer of information using computer, Internet, and other technical devices increases the risk of interception of confidential information by others. Information confidentiality problem is one of the main conditions of provision of information security. People working with information resources must comprehend their responsibility to protect the confidentiality of information belonging to different citizens or organizations.

Culture Presentation of Information (C_5). A person demonstrates possession of rich knowledge, valuable information, when he/she can present carried knowledge and information to society. Information presentation is usually carried out through oral speech and writing, each of which has its own characteristics. The person mastering these characteristics well can present information on a perfect level. For example, information presentation skills of a person can be highly evaluated, when information is clear to those being presented to; that is, it is composed of simple and substantial sentences, excessive use of special terms being avoided, and carried ideas which are consecutive and complete each other. At the same time, field related to the presented information must be well researched, analyzed, and referred to when necessary.

Step 2 (establish a group of decision-makers). Let A_i ($i = 1, \ldots, n$) be a finite set of n alternatives which are to be evaluated by a group of K decision-makers DM_k ($k = 1, \ldots, K$) with respect to a set of m evaluation criteria C_j ($j = 1, \ldots, m$).

Step 3 (identify the linguistic variables). Identify the appropriate linguistic variables for the importance weight of criteria and the rating for alternatives with regard to each criterion. The decision-makers used TFN linguistic variables shown in Tables 1 and 2 to evaluate the importance of the criteria and the performance ratings of alternatives with respect to qualitative criteria.

Step 4 (construct the performance rating matrix). A typical fuzzy MCDM problem is formally expressed in matrix format as $\widetilde{\mathbf{X}}_k = \|\widetilde{x}_{ijk}\|$, where $\widetilde{x}_{ijk}$ is the fuzzy performance rating of alternative A_i with respect to criterion C_j evaluated by kth decision-maker DM_k. $\widetilde{x}_{ijk} = (x^l_{ijk}, x^m_{ijk}, x^u_{ijk})$ is a linguistic variable denoted by TFNs.

Table 2: Linguistic variables for the performance ratings of alternatives.

Linguistic variables	Corresponding TFNs
Best	(8, 9, 10)
Good	(6, 7, 8)
Fair	(4, 5, 6)
Poor	(2, 3, 4)
Worst	(1, 1, 2)

Step 5 (calculate aggregate fuzzy ratings for the alternatives). The aggregated fuzzy performance rating $\tilde{x}_{ijk} = (x^l_{ijk}, x^m_{ijk}, x^u_{ijk})$ of each alternative can be calculated as follows:

$$x^l_{ij} = \frac{1}{K}\sum_{k=1}^{K} x^l_{ijk},$$
$$x^m_{ij} = \frac{1}{K}\sum_{k=1}^{K} x^m_{ijk}, \quad (24)$$
$$x^u_{ij} = \frac{1}{K}\sum_{k=1}^{K} x^u_{ijk}.$$

Step 6 (determine the fuzzy best value and the fuzzy worst value of all criteria). The fuzzy best value and the fuzzy worst value are determined, respectively, as

$$\tilde{x}^+_j = \begin{cases} \max\limits_{i=1,\dots,n}\left\{\tilde{x}_{ij}\right\}, & \text{for benefit criterion,} \\ \min\limits_{i=1,\dots,n}\left\{\tilde{x}_{ij}\right\}, & \text{for cost criterion,} \end{cases} \quad (25)$$

$$\tilde{x}^-_j = \begin{cases} \min\limits_{i=1,\dots,n}\left\{\tilde{x}_{ij}\right\}, & \text{for benefit criterion,} \\ \max\limits_{i=1,\dots,n}\left\{\tilde{x}_{ij}\right\}, & \text{for cost criterion,} \end{cases} \quad (26)$$

$$j = 1, \dots, m,$$

where $\tilde{x}^+_j$ is the fuzzy positive-ideal solution and $\tilde{x}^-_j$ is the fuzzy negative-ideal solution for jth criteria.

Step 7 (calculate the utility and the regret measures). The VIKOR ranking implies that the preferred alternative is proximate to the ideal solution, starting from L^p-metric used as an aggregating function in a compromise programming method as follows:

$$L^p_i = \left\{\sum_{j=1}^{m}\left|\frac{\tilde{w}_j\left(\tilde{x}^+_j - \tilde{x}_{ij}\right)}{\left(\tilde{x}^+_j - \tilde{x}^-_j\right)}\right|^p\right\}^{1/p}, \quad (27)$$
$$1 \le p \le \infty;\ i = 1, \dots, n.$$

In the VIKOR method, $L^{p=1}_i$ as $\tilde{S}_i$ and $L^{p=\infty}_i$ as $\tilde{R}_i$ are used to formulate the ranking measure. Consider

$$\tilde{S}_i = \sum_{j=1}^{m}\left|\frac{\tilde{w}_j\left(\tilde{x}^+_j - \tilde{x}_{ij}\right)}{\left(\tilde{x}^+_j - \tilde{x}^-_j\right)}\right|, \quad (28)$$

$$\tilde{R}^{\mathrm{V}}_i = \max_{j=1,\dots,m}\left|\frac{\tilde{w}_j\left(\tilde{x}^+_j - \tilde{x}_{ij}\right)}{\left(\tilde{x}^+_j - \tilde{x}^-_j\right)}\right|, \quad i = 1, \dots, n, \quad (29)$$

where $\tilde{w}_j$ are the weights of criteria, expressing the decision-makers' preference as the relative importance of the criteria, and $\tilde{S}_i$ and $\tilde{R}_i$ represent the utility measure and the regret measure. $\tilde{S}_i$ is shown as the average gap; $\tilde{R}_i$ is shown as maximal gap for improvement priority. $\tilde{S}_i$ refers to the separation measure of A_i from the positive-ideal solution; $\tilde{R}_i$ is the separation measure of A_i from the negative-ideal solution. $\tilde{S}_i$ and $\tilde{R}_i$ are used to formulate ranking measure.

To calculate the utility measure ($\tilde{S}_i$) and the regret measure ($\tilde{R}_i$), the VIKOR method uses different metrics $L^{p=1}$ and $L^{p=\infty}$. On the other hand, from (28) and (29), it follows that for any i, $\tilde{S}_i > \tilde{R}_i$; that is, this definition imposes a precondition that each alternative will be close to the negative-ideal solution compared to the positive-ideal solution. As is known it cannot describe the real situation. Consequently, in this study, to formulate the ranking instead of (29), we propose the following measure as separation distance of alternative from negative-ideal solution:

$$\tilde{R}^{\mathrm{MV}}_i = \sum_{j=1}^{m}\left|\frac{\tilde{w}_j\left(\tilde{x}_{ij} - \tilde{x}^-_j\right)}{\left(\tilde{x}^+_j - \tilde{x}^-_j\right)}\right|, \quad i = 1, \dots, n. \quad (30)$$

Step 8 (compute the values $\tilde{Q}_i$). For ranking the results, we use the following VIKOR index $\tilde{Q}^{\mathrm{V}}_i$ and modified VIKOR index $\tilde{Q}^{\mathrm{MV}}_i$:

$$\tilde{Q}^{\mathrm{V}}_i = \lambda\frac{\tilde{S}_i - \tilde{S}^-}{\tilde{S}^+ - \tilde{S}^-} + (1-\lambda)\frac{\tilde{R}^{\mathrm{V}}_i - \tilde{R}^{\mathrm{V}-}}{\tilde{R}^{\mathrm{V}+} - \tilde{R}^{\mathrm{V}-}}, \quad i = 1, \dots, n, \quad (31)$$

$$\tilde{Q}^{\mathrm{MV}}_i = \lambda\frac{\tilde{S}_i - \tilde{S}^-}{\tilde{S}^+ - \tilde{S}^-} + (1-\lambda)\frac{\tilde{R}^{\mathrm{MV}}_i - \tilde{R}^{\mathrm{MV}-}}{\tilde{R}^{\mathrm{MV}+} - \tilde{R}^{\mathrm{MV}-}}, \quad i = 1, \dots, n, \quad (32)$$

where

$$\begin{aligned} \tilde{S}^+ &= \max_{i=1,\dots,n}\left\{\tilde{S}_i\right\}, \\ \tilde{S}^- &= \min_{i=1,\dots,n}\left\{\tilde{S}_i\right\}, \\ \tilde{R}^{\mathrm{V}+} &= \max_{i=1,\dots,n}\left\{\tilde{R}^{\mathrm{V}}_i\right\}, \\ \tilde{R}^{\mathrm{V}-} &= \min_{i=1,\dots,n}\left\{\tilde{R}^{\mathrm{V}}_i\right\}, \\ \tilde{R}^{\mathrm{MV}+} &= \max_{i=1,\dots,n}\left\{\tilde{R}^{\mathrm{MV}}_i\right\}, \\ \tilde{R}^{\mathrm{MV}-} &= \min_{i=1,\dots,n}\left\{\tilde{R}^{\mathrm{MV}}_i\right\}. \end{aligned} \quad (33)$$

The solution obtained by $\tilde{S}^+$ belongs to a maximum group utility ("majority" rule), the solution obtained by $\tilde{R}^+$

belongs to a minimum individual regret of the "opponent," and $\lambda \in [0,1]$ is the weight of the decision-making strategy "the majority of criteria" (or "the maximum group utility"). Generally, $\lambda = 0.5$, which can be adjusted depending on the case; $\lambda = 1$ indicates that only the average gap is considered, and $\lambda = 0$ indicates that only the maximum gap is prioritized for improvement. The compromise final solution can be investigated and then selected with "voting by majority" ($\lambda > 0.5$), with "consensus" ($\lambda = 0.5$) and with "veto" ($\lambda < 0.5$). To evaluate VIKOR stability, it is helpful to arrange ranking orders according to the three different values of λ. Yazdani and Payam [56] showed that the ranking scores produced by different values of λ in VIKOR are very close to each other which mean that the ranking based on values of λ does not affect the rank of the best choice.

After simple transformations, from (31) can be expressed as (34):

$$\begin{aligned}\widetilde{Q}_i^{\mathrm{V}} &= \frac{\lambda}{\widetilde{S}^+ - \widetilde{S}^-}\widetilde{S}_i + \frac{1-\lambda}{\widetilde{R}^{\mathrm{V}+} - \widetilde{R}^{\mathrm{V}-}}\widetilde{R}_i^{\mathrm{V}} \\ &\quad + \lambda\left(\frac{\widetilde{R}^{\mathrm{V}+}}{\widetilde{R}^{\mathrm{V}+} - \widetilde{R}^{\mathrm{V}-}} - \frac{\widetilde{S}^-}{\widetilde{S}^+ - \widetilde{S}^-}\right) - \frac{\widetilde{R}^{\mathrm{V}+}}{\widetilde{R}^{\mathrm{V}+} - \widetilde{R}^{\mathrm{V}-}} \\ &= \alpha_1\widetilde{S}_i + \alpha_2\widetilde{R}_i^{\mathrm{V}} + \Delta,\end{aligned} \tag{34}$$

where

$$\begin{aligned}\alpha_1 &= \frac{\lambda}{\widetilde{S}^+ - \widetilde{S}^-}, \\ \alpha_2 &= \frac{1-\lambda}{\widetilde{R}^{\mathrm{V}+} - \widetilde{R}^{\mathrm{V}-}}, \\ \Delta &= \lambda\left(\frac{\widetilde{R}^{\mathrm{V}+}}{\widetilde{R}^{\mathrm{V}+} - \widetilde{R}^{\mathrm{V}-}} - \frac{\widetilde{S}^-}{\widetilde{S}^+ - \widetilde{S}^-}\right) - \frac{\widetilde{R}^{\mathrm{V}+}}{\widetilde{R}^{\mathrm{V}+} - \widetilde{R}^{\mathrm{V}-}}.\end{aligned} \tag{35}$$

From (35), we observe that for any i ($i = 1,\dots,n$) $\Delta =$ const, $\alpha_1 =$ const, and $\alpha_2 =$ const. Thus, we conclude that $\widetilde{Q}_i^{\mathrm{V}}$ is the linear combination of $\widetilde{S}_i$ and $\widetilde{R}_i$. Therefore, to obtain compromise ranking instead of (31) and (32), we can use the following indices, defined as a linear combination of the measures $\widetilde{S}_i$ and $\widetilde{R}_i$:

$$\widetilde{Q}_i^{\mathrm{LV}} = \lambda\cdot\widetilde{S}_i + (1-\lambda)\cdot\widetilde{R}_i^{\mathrm{V}}, \tag{36}$$

$$\widetilde{Q}_i^{\mathrm{LMV}} = \lambda\cdot\widetilde{S}_i + (1-\lambda)\cdot\widetilde{R}_i^{\mathrm{MV}}. \tag{37}$$

Analogously to TOPSIS method [29], to rank the alternatives, the following indices also will be used:

$$\widetilde{Q}_i^{\mathrm{TV}} = \frac{\widetilde{S}_i}{\widetilde{S}_i + \widetilde{R}_i^{\mathrm{V}}}, \tag{38}$$

$$\widetilde{Q}_i^{\mathrm{TMV}} = \frac{\widetilde{S}_i}{\widetilde{S}_i + \widetilde{R}_i^{\mathrm{MV}}}. \tag{39}$$

It is easy to see that, from a computational complexity point of view, the presented modified VIKOR models (36)–(39) are more effective than the original fuzzy VIKOR model (31).

Step 9 (defuzzification). Using (23), defuzzify TFNs $\widetilde{S}_i = (S_i^l, S_i^m, S_i^u)$, $\widetilde{R}_i = (R_i^l, R_i^m, R_i^u)$, and $\widetilde{Q}_i = (Q_i^l, Q_i^m, Q_i^u)$ as follows:

$$\begin{aligned}S_i &= \frac{S_i^l + S_i^m + S_i^u}{3}; \\ R_i &= \frac{R_i^l + R_i^m + R_i^u}{3}; \\ Q_i &= \frac{Q_i^l + Q_i^m + Q_i^u}{3}.\end{aligned} \tag{40}$$

Step 10 (rank the alternatives). Rank the alternatives, sorting them by the values Q, S, and R in ascending order. The results are six ranking lists. The index Q_i implies the separation measure of A_i from the best alternative. That is, the smaller the value Q, the better the alternative.

Step 11 (propose the compromise solution). If the following two conditions are satisfied, then the scheme with a minimum value of $\widetilde{Q}$ in ranking is considered the optimal compromise solution according to [57]

(**C1**) *acceptable advantage*: the alternative $A^{(1)}$ has an acceptable advantage, if $(\widetilde{Q}(A^{(2)}) - \widetilde{Q}(A^{(1)}))/(\widetilde{Q}(A^{(n)}) - \widetilde{Q}(A^{(1)})) \geq 1/(n-1)$, where $A^{(1)}$ is the best ranked alternative and $A^{(2)}$ is the alternative with second position in the ranking list by the measure $\widetilde{Q}$; n is the number of alternatives;

(**C2**) *acceptable stability*: the alternative $A^{(1)}$ must also be the best ranked by S or/and R. The compromise solution is stable within decision-making process, which could be with "voting by majority rule" (when $\lambda > 0.5$ is needed) or by "consensus" (when $\lambda = 0.5$) and with "veto" (when $\lambda < 0.5$).

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of

(i) alternatives $A^{(1)}$ and $A^{(2)}$ if only condition (**C2**) is not satisfied, or

(ii) alternatives $A^{(1)},\dots,A^{(M)}$ if condition (**C1**) is not satisfied; $A^{(M)}$ is determined by the relation $\widetilde{Q}(A^{(M)}) - \widetilde{Q}(A^{(1)}) \approx 1/(n-1)$ for maximum M (the positions of these alternatives are "in closeness").

5. Calculate the Weights of Criteria: Worst-Case Method

The idea of the worst-case method [23] is borrowed from structural system analysis, where the reliability of a system is distributed among its elements according to their ranks. The higher the rank is, the greater the reliability part is. Unlike previous methods [27, 29, 32, 58], where for determination of the weights of criteria has been used technique of paired comparison, this method compares criteria only with the one that is the least important among them.

Let w_j^k be the weight of the criterion C_j given by the decision-maker DM_k that reflects its importance. Let us suppose that the larger the weight w_j^k of the criterion C_j is, the higher rank its rank R_j^k is. This is formalized by the relation

$$\frac{w_1^k}{R_1^k} = \frac{w_2^k}{R_2^k} = \cdots = \frac{w_q^k}{R_q^k} = \cdots = \frac{w_m^k}{R_m^k}. \quad (41)$$

Let w_q^k and R_q^k represent the weight and the rank of the least important criterion, respectively, evaluated by the decision-maker DM_k. From (40), we obtain the following expression for the weights of criteria relative to the least important criterion, evaluated by the decision-maker DM_k:

$$\begin{aligned} w_1^k &= R_1^k \frac{w_q^k}{R_q^k}, \\ w_2^k &= R_2^k \frac{w_q^k}{R_q^k}, \\ &\vdots \\ w_m^k &= R_m^k \frac{w_q^k}{R_q^k}, \\ & \qquad k = 1, 2, \ldots, K. \end{aligned} \quad (42)$$

Let us require the following condition to hold:

$$w_1^k + w_2^k + \cdots + w_q^k + \cdots + w_m^k = 1, \quad k = 1, 2, \ldots, K. \quad (43)$$

Substituting (41) into (42), we obtain the weight of the least important criterion. One has

$$\begin{aligned} w_q^k &= \frac{1}{R_1^k/R_q^k + R_2^k/R_q^k + \cdots + R_m^k/R_q^k} \\ &= \frac{1}{\sum_{j=1}^{m} \left(R_j^k / R_q^k \right)}, \quad k = 1, 2, \ldots, K. \end{aligned} \quad (44)$$

Equations (42) and (44) allow one to calculate the criteria weights using ratios of the ranks of all criteria C_j to the rank of the least important criterion C_q. Note that comparison with the least important case guarantees that the condition $R_j^k/R_q^k \geq 1$ holds for all $j = 1, 2, \ldots, m$ and $k = 1, 2, \ldots, K$.

In (44), the ratios R_j^k/R_q^k of criteria ranks are estimated using Saaty's 1–9 scales [27, 28]. The 1–9 scales are illustrated in Table 1.

From (42) and (44), using (21), we obtain the following aggregated weights of criteria:

$$w_j = \frac{1}{K} \sum_{k=1}^{K} w_j^k, \quad j = 1, 2, \ldots, m. \quad (45)$$

6. An Empirical Study

The purpose of the empirical study is to illustrate the use of the suggested method. The experiment was basically set up upon a real life decision. We have formed an executive committee consisting of five independent decision-makers DM_k ($k = 1, \ldots, 5$) to choose the best alternative from another five participants (Ph.D. students) (A_i, $i = 1, \ldots, 5$) to fill the vacancy in the Training-Innovation Centre of the Institute of Information Technology of Azerbaijan National Academy of Sciences. We have selected five Ph.D. students in different areas (mathematics, linguistics, pedagogy, computer science, and medicine) and three specialists in the fields of information security, pedagogy and educational management, and mathematics from the Training-Innovation Centre of the Institute of Information Technology of Azerbaijan National Academy of Sciences, together with two authors of this paper to set up a creative team to participate in this evaluation.

TABLE 3: Individual fuzzy decision matrix of DM_1.

Alternatives	Criteria				
	C_1	C_2	C_3	C_4	C_5
A_1	(6, 7, 8)	(4, 5, 6)	(4, 5, 6)	(2, 3, 4)	(6, 7, 8)
A_2	(4, 5, 6)	(8, 9, 10)	(4, 5, 6)	(6, 7, 8)	(6, 7, 8)
A_3	(6, 7, 8)	(6, 7, 8)	(2, 3, 4)	(4, 5, 6)	(8, 9, 10)
A_4	(2, 3, 4)	(1, 1, 2)	(6, 7, 8)	(4, 5, 6)	(4, 5, 6)
A_5	(4, 5, 6)	(2, 3, 4)	(1, 1, 2)	(6, 7, 8)	(4, 5, 6)

6.1. Formation of the Initial Decision Matrices. As reported above, five decision-makers are asked to evaluate the alternatives with respect to the criteria $C_1 \div C_5$, respectively, using abovementioned linguistic terms reported in Tables 1 and 2.

6.2. Aggregation of the Decision Matrices. Table 8 shows the aggregated fuzzy ratings of the alternatives by decision-makers obtained from Tables 3–7. The aggregated fuzzy rating is calculated using (21).

Moreover positive-ideal ($\widetilde{X}^+$) and negative-ideal ($\widetilde{X}^-$) solutions are identified. The fuzzy positive-ideal solution ($\widetilde{X}^+$) and the fuzzy negative-ideal solution ($\widetilde{X}^-$) are calculated using (25) and (26).

6.3. Calculation of the Criteria Weights. For calculation of the criteria weights by the worst-case method, the decision-makers independently identified the least important criterion and accordingly its rank. Then, using Saaty's scales, they determined rank of other criteria relative to the least important criterion. Table 9 represents the ranks of criteria assigned by each decision-maker.

As seen from Table 9 for decision-makers DM_1, DM_2, DM_3, DM_4, and DM_5, the least important criteria are C_5, C_3, C_2, C_4, and C_1, respectively. From Table 9, by applying (42) and (44), we obtain the following weights of criteria (Table 10).

All these criteria are benefit criteria. All the calculations were carried out using MS Excel.

6.4. Evaluation Results and Discussion. For different values of $\lambda = 0.1$, 0.5, and 0.9, the values of S, R, and Q are

Table 4: Individual fuzzy decision matrix of DM_2.

Alternatives	Criteria C_1	C_2	C_3	C_4	C_5
A_1	(4, 5, 6)	(2, 3, 4)	(1, 1, 2)	(2, 3, 4)	(4, 5, 6)
A_2	(2, 3, 4)	(6, 7, 8)	(2, 3, 4)	(2, 3, 4)	(4, 5, 6)
A_3	(8, 9, 10)	(4, 5, 6)	(6, 7, 8)	(4, 5, 6)	(2, 3, 4)
A_4	(1, 1, 2)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(6, 7, 8)
A_5	(6, 7, 8)	(4, 5, 6)	(2, 3, 4)	(8, 9, 10)	(4, 5, 6)

Table 5: Individual fuzzy decision matrix of DM_3.

Alternatives	Criteria C_1	C_2	C_3	C_4	C_5
A_1	(8, 9, 10)	(4, 5, 6)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)
A_2	(6, 7, 8)	(1, 1, 2)	(4, 5, 6)	(2, 3, 4)	(4, 5, 6)
A_3	(2, 3, 4)	(6, 7, 8)	(4, 5, 6)	(1, 1, 2)	(8, 9, 10)
A_4	(4, 5, 6)	(8, 9, 10)	(6, 7, 8)	(6, 7, 8)	(4, 5, 6)
A_5	(2, 3, 4)	(4, 5, 6)	(2, 3, 4)	(8, 9, 10)	(2, 3, 4)

Table 6: Individual fuzzy decision matrix of DM_4.

Alternatives	Criteria C_1	C_2	C_3	C_4	C_5
A_1	(4, 5, 6)	(2, 3, 4)	(8, 9, 10)	(6, 7, 8)	(4, 5, 6)
A_2	(6, 7, 8)	(2, 3, 4)	(6, 7, 8)	(4, 5, 6)	(2, 3, 4)
A_3	(8, 9, 10)	(6, 7, 8)	(4, 5, 6)	(4, 5, 6)	(4, 5, 6)
A_4	(4, 5, 6)	(8, 9, 10)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)
A_5	(2, 3, 4)	(4, 5, 6)	(2, 3, 4)	(6, 7, 8)	(8, 9, 10)

Table 7: Individual fuzzy decision matrix of DM_5.

Alternatives	Criteria C_1	C_2	C_3	C_4	C_5
A_1	(6, 7, 8)	(2, 3, 4)	(6, 7, 8)	(4, 5, 6)	(6, 7, 8)
A_2	(2, 3, 4)	(6, 7, 8)	(4, 5, 6)	(1, 1, 2)	(4, 5, 6)
A_3	(8, 9, 10)	(4, 5, 6)	(4, 5, 6)	(6, 7, 8)	(2, 3, 4)
A_4	(1, 1, 2)	(2, 3, 4)	(6, 7, 8)	(4, 5, 6)	(6, 7, 8)
A_5	(6, 7, 8)	(4, 5, 6)	(2, 3, 4)	(6, 7, 8)	(4, 5, 6)

calculated using (28)–(40). Then their fuzzy values, using (23), are defuzzified into crisp values and listed in Tables 11–14. The comparison among the different ranking strategies is also shown in Tables 11–14. In these tables bracket [·] denotes the ranking order.

From Tables 12–14, we observe the following main results:

(i) For all values of λ, A_3 is ranked best alternative when the ranking strategies Q^{V} and Q^{LV} are used. And these strategies demonstrate close results for all values of λ (closeness will be assessed by Kendal rank correlation below). It is very interesting result! This confirms the rightness of the proposed modification!

(ii) When $\lambda = 0.5$ and $\lambda = 0.9$, the Q^{V}, Q^{LV}, Q^{MV}, and Q^{LMV} methods demonstrate close results. And when $\lambda = 0.9$, ordering of the alternatives by the Q^{V} and Q^{MV} methods and, respectively, by the Q^{LV} and Q^{LMV} methods is the same. This result again confirms the rightness of the proposed modification of the VIKOR method.

(iii) For $\lambda = 0.1$ and $\lambda = 0.5$ A_3 is ranked as best alternative when the ranking strategies Q^{MV} and Q^{LMV} are used.

(iv) Ordering of the alternatives by the S, Q^{TMV}, $Q^{LV}_{\lambda=0.5}$, $Q^{V}_{\lambda=0.1}$, $Q^{LV}_{\lambda=0.9}$, and $Q^{LMV}_{\lambda=0.9}$ methods is the same.

Another interesting result is obtained by averaging the results for different values of λ. Table 15 gives a comparative analysis of the alternatives judged by the average values $\overline{Q}^{V}$, $\overline{Q}^{LV}$, $\overline{Q}^{MV}$, and $\overline{Q}^{LMV}$ which are obtained from Tables 12–14 as follows:

$$\begin{aligned}
\overline{Q}^{V} &= \frac{\left(Q^{V}_{\lambda=0.1} + Q^{V}_{\lambda=0.5} + Q^{V}_{\lambda=0.9}\right)}{3};\\
\overline{Q}^{LV} &= \frac{\left(Q^{LV}_{\lambda=0.1} + Q^{LV}_{\lambda=0.5} + Q^{LV}_{\lambda=0.9}\right)}{3};\\
\overline{Q}^{MV} &= \frac{\left(Q^{MV}_{\lambda=0.1} + Q^{MV}_{\lambda=0.5} + Q^{MV}_{\lambda=0.9}\right)}{3};\\
\overline{Q}^{LMV} &= \frac{\left(Q^{LMV}_{\lambda=0.1} + Q^{LMV}_{\lambda=0.5} + Q^{LMV}_{\lambda=0.9}\right)}{3}.
\end{aligned} \tag{46}$$

Looking at Tables 13 and 15, we find that the average values $\overline{Q}^{V}$, $\overline{Q}^{LV}$, $\overline{Q}^{MV}$, and $\overline{Q}^{LMV}$ are equal to the values $Q^{V}_{\lambda=0.5}$, $Q^{LV}_{\lambda=0.5}$, $Q^{MV}_{\lambda=0.5}$, and $Q^{LMV}_{\lambda=0.5}$, respectively. The coincidence of the values $\overline{Q}^{LV}$ and $Q^{V}_{\lambda=0.5}$, $\overline{Q}^{LMV}$, and $Q^{LMV}_{\lambda=0.5}$ is obvious. It can be directly derived from (36). Indeed, let us have P values of Q for P values of λ. Consider

$$Q_p = \lambda_p \cdot S + \left(1 - \lambda_p\right) \cdot R, \quad p = 1, \ldots, P; \tag{47}$$

then the average value $\overline{Q}$ can be calculated as

$$\overline{Q} = S \times \frac{1}{P} \sum_{p=1}^{P} \lambda_p + R \times \frac{1}{P} \sum_{p=1}^{P} \left(1 - \lambda_p\right). \tag{48}$$

The last expression shows that the average value $\overline{Q}$ is a linear combination of S and R multiplied by the average values of the parameters λ_p and $(1 - \lambda_p)$, respectively. In this experiment the average value of λ is equal to $(0.1 + 0.5 + 0.9)/3 = 0.5$. Consequently, the ranks of alternatives with respect to the average values $\overline{Q}^{LV}$ and $\overline{Q}^{LMV}$ (Table 15) must coincide with the ranks, corresponding to the values $Q^{LV}_{\lambda=0.5}$ and $Q^{LMV}_{\lambda=0.5}$ (Table 13).

Here, an interesting fact is that the average values $\overline{Q}^{V}$ and $\overline{Q}^{MV}$ are also equal to the values $Q^{V}_{\lambda=0.5}$ and $Q^{MV}_{\lambda=0.5}$, respectively. This fact once again confirms rightness of our approach that the simple way computing Q is the linear combination of S and R.

Table 8: Aggregated fuzzy performance ratings of the alternatives.

Alternatives	Criteria C_1	C_2	C_3	C_4	C_5
A_1	(5.60, 6.60, 7.60)	(2.80, 3.80, 4.80)	(4.20, 5.00, 6.00)	(3.60, 4.60, 5.60)	(5.20, 6.20, 7.20)
A_2	(4.00, 5.00, 6.00)	(4.60, 5.40, 6.40)	(4.00, 5.00, 6.00)	(3.00, 3.80, 4.80)	(4.00, 5.00, 6.00)
A_3	(6.40, 7.40, 8.40)	(5.20, 6.20, 7.20)	(4.00, 5.00, 6.00)	(3.80, 4.60, 5.60)	(4.80, 5.80, 6.80)
A_4	(2.40, 3.00, 4.00)	(4.20, 5.00, 6.00)	(4.80, 5.80, 6.80)	(4.80, 5.80, 6.80)	(5.20, 6.20, 7.20)
A_5	(4.00, 5.00, 6.00)	(3.60, 4.60, 5.60)	(1.80, 2.60, 3.60)	(6.80, 7.80, 8.80)	(4.40, 5.40, 6.40)
$\widetilde{X}^{+}$	(6.40, 7.40, 8.40)	(5.20, 6.20, 7.20)	(4.80, 5.80, 6.80)	(6.80, 7.80, 8.80)	(5.20, 6.20, 7.20)
$\widetilde{X}^{-}$	(2.40, 3.00, 4.00)	(2.80, 3.80, 4.80)	(1.80, 2.60, 3.60)	(3.00, 3.80, 4.80)	(4.00, 5.00, 6.00)

Table 9: The ranks of criteria assigned by each decision maker.

Criteria	The relative importance of the criteria defined by each decision-maker DM$_1$ R_j/R_5	DM$_2$ R_j/R_3	DM$_3$ R_j/R_2	DM$_4$ R_j/R_4	DM$_5$ R_j/R_1
C_1	2	8	5	3	**1**
C_2	6	4	**1**	2	3
C_3	7	**1**	3	6	7
C_4	3	5	8	**1**	2
C_5	**1**	7	6	8	4

From Table 15, we obtain the final ranking of alternatives obtained by different methods (Table 16).

From Table 16, we see that A_3 is ranked as best alternative when $Q^{\mathrm{V}}, Q^{\mathrm{LV}}, Q^{\mathrm{MV}}, Q^{\mathrm{LMV}}$, and Q^{TMV} methods are used, and A_2 is ranked as best alternative when Q^{TV} method is used.

Table 17 demonstrates Kendall rank correlation between different methods [59].

As seen in Table 17, high correlation is obtained between the Q^{V} and Q^{LV} and between the Q^{V} and Q^{TMV} measures.

Checking condition (**C1**) (acceptable advantage),

$$\begin{aligned}
&\frac{Q^{\mathrm{TV}}(A^{(2)}) - Q^{\mathrm{TV}}(A^{(1)})}{Q^{\mathrm{TV}}(A^{(5)}) - Q^{\mathrm{TV}}(A^{(1)})} = \frac{Q^{\mathrm{TV}}(A_3) - Q^{\mathrm{TV}}(A_2)}{Q^{\mathrm{TV}}(A_1) - Q^{\mathrm{TV}}(A_2)} \\
&\quad = \frac{1.2970 - 1.2899}{2.1942 - 1.2899} = \frac{0.0071}{0.9043} = 0.0079 < \frac{1}{(n-1)} \\
&\quad = \frac{1}{(5-1)} = 0.25, \\
&\frac{Q^{\mathrm{TMV}}(A^{(2)}) - Q^{\mathrm{TMV}}(A^{(1)})}{Q^{\mathrm{TMV}}(A^{(5)}) - Q^{\mathrm{TMV}}(A^{(1)})} \\
&\quad = \frac{Q^{\mathrm{TMV}}(A_4) - Q^{\mathrm{TMV}}(A_3)}{Q^{\mathrm{TMV}}(A_5) - Q^{\mathrm{TMV}}(A_3)} = \frac{0.6830 - 0.6027}{0.9370 - 0.6027} \\
&\quad = \frac{0.0803}{0.3343} = 0.2402 < 0.25;
\end{aligned} \tag{49}$$

for $\lambda = 0.5$,

$$\begin{aligned}
&\frac{Q^{\mathrm{V}}_{\lambda=0.5}(A^{(2)}) - Q^{\mathrm{V}}_{\lambda=0.5}(A^{(1)})}{Q^{\mathrm{V}}_{\lambda=0.5}(A^{(5)}) - Q^{\mathrm{V}}_{\lambda=0.5}(A^{(1)})} \\
&\quad = \frac{Q^{\mathrm{V}}_{\lambda=0.5}(A_4) - Q^{\mathrm{V}}_{\lambda=0.5}(A_3)}{Q^{\mathrm{V}}_{\lambda=0.5}(A_5) - Q^{\mathrm{V}}_{\lambda=0.5}(A_3)} = \frac{0.5508 - 0.3633}{0.8988 - 0.3633} \\
&\quad = \frac{0.1875}{0.5355} = 0.3501 \geq 0.25, \\
&\frac{Q^{\mathrm{LV}}_{\lambda=0.5}(A^{(2)}) - Q^{\mathrm{LV}}_{\lambda=0.5}(A^{(1)})}{Q^{\mathrm{LV}}_{\lambda=0.5}(A^{(5)}) - Q^{\mathrm{LV}}_{\lambda=0.5}(A^{(1)})} \\
&\quad = \frac{Q^{\mathrm{LV}}_{\lambda=0.5}(A_4) - Q^{\mathrm{LV}}_{\lambda=0.5}(A_3)}{Q^{\mathrm{LV}}_{\lambda=0.5}(A_5) - Q^{\mathrm{LV}}_{\lambda=0.5}(A_3)} = \frac{0.7180 - 0.5663}{0.9219 - 0.5663} \\
&\quad = \frac{0.1517}{0.3556} = \mathbf{0.4266} \geq 0.25, \\
&\frac{Q^{\mathrm{MV}}_{\lambda=0.5}(A^{(2)}) - Q^{\mathrm{MV}}_{\lambda=0.5}(A^{(1)})}{Q^{\mathrm{MV}}_{\lambda=0.5}(A^{(5)}) - Q^{\mathrm{MV}}_{\lambda=0.5}(A^{(1)})} \\
&\quad = \frac{Q^{\mathrm{MV}}_{\lambda=0.5}(A_5) - Q^{\mathrm{MV}}_{\lambda=0.5}(A_3)}{Q^{\mathrm{MV}}_{\lambda=0.5}(A_4) - Q^{\mathrm{MV}}_{\lambda=0.5}(A_3)} = \frac{0.6061 - 0.5192}{0.6469 - 0.5192} \\
&\quad = \frac{0.0862}{0.1277} = 0.6805 \geq 0.25, \\
&\frac{Q^{\mathrm{LMV}}_{\lambda=0.5}(A^{(2)}) - Q^{\mathrm{LMV}}_{\lambda=0.5}(A^{(1)})}{Q^{\mathrm{LMV}}_{\lambda=0.5}(A^{(5)}) - Q^{\mathrm{LMV}}_{\lambda=0.5}(A^{(1)})} \\
&\quad = \frac{Q^{\mathrm{LMV}}_{\lambda=0.5}(A_1) - Q^{\mathrm{LMV}}_{\lambda=0.5}(A_3)}{Q^{\mathrm{LMV}}_{\lambda=0.5}(A_4) - Q^{\mathrm{LMV}}_{\lambda=0.5}(A_3)} = \frac{1.0735 - 1.0313}{1.1511 - 1.0313} \\
&\quad = \frac{0.0422}{0.1198} = 0.3522 \geq 0.25;
\end{aligned} \tag{50}$$

for $\lambda = 0.1$,

$$\begin{aligned}
&\frac{Q^{\mathrm{V}}_{\lambda=0.1}(A^{(2)}) - Q^{\mathrm{V}}_{\lambda=0.1}(A^{(1)})}{Q^{\mathrm{V}}_{\lambda=0.1}(A^{(5)}) - Q^{\mathrm{V}}_{\lambda=0.1}(A^{(1)})} \\
&\quad = \frac{Q^{\mathrm{V}}_{\lambda=0.1}(A_4) - Q^{\mathrm{V}}_{\lambda=0.1}(A_3)}{Q^{\mathrm{V}}_{\lambda=0.1}(A_5) - Q^{\mathrm{V}}_{\lambda=0.1}(A_3)} = \frac{0.6082 - 0.3510}{0.9581 - 0.3510}
\end{aligned}$$

Table 10: Importance weights of evaluation criteria.

The weights of criteria for each decision-maker (w_j^k)					The average weights of criteria (w_j)
DM$_1$	DM$_2$	DM$_3$	DM$_4$	DM$_5$	
$w_1^1 = 0.1053$	$w_1^2 = 0.3200$	$w_1^3 = 0.2174$	$w_1^4 = 0.1500$	$w_1^5 = 0.0588$	$w_1 = 0.1703$
$w_2^1 = 0.3158$	$w_2^2 = 0.1600$	$w_2^3 = 0.0435$	$w_2^4 = 0.1000$	$w_2^5 = 0.1765$	$w_2 = 0.1591$
$w_3^1 = 0.3684$	$w_3^2 = 0.0400$	$w_3^3 = 0.1304$	$w_3^4 = 0.3000$	$w_3^5 = 0.4118$	$w_3 = 0.2501$
$w_4^1 = 0.1579$	$w_4^2 = 0.2000$	$w_4^3 = 0.3478$	$w_4^4 = 0.0500$	$w_4^5 = 0.1176$	$w_4 = 0.1747$
$w_5^1 = 0.0526$	$w_5^2 = 0.2800$	$w_5^3 = 0.2609$	$w_5^4 = 0.4000$	$w_5^5 = 0.2353$	$w_5 = 0.2458$

Table 11: Ranking of alternatives with respect to values of S, R^{V}, Q^{TV}, Q^{TMV}, and Q^{TMV}.

Alternatives	S (26)		R^{V} (27)		R^{MV} (28)		Q^{TV} (38)		Q^{TMV} (39)	
A_1	1.1636	[4]	0.6484	[5]	0.9834	[4]	2.1942	[5]	0.8326	[4]
A_2	1.1038	[3]	0.4467	[2]	1.1005	[3]	**1.2899**	[**1**]	0.8033	[3]
A_3	**0.8088**	[**1**]	**0.3238**	[**1**]	1.2538	[2]	1.2970	[2]	**0.6027**	[**1**]
A_4	0.9587	[2]	0.4772	[3]	**1.3434**	[**1**]	1.9910	[4]	0.6830	[2]
A_5	1.2630	[5]	0.5807	[4]	0.9433	[5]	1.6891	[3]	0.9370	[5]

Table 12: Ranking of alternatives with respect to values of Q^{V}, Q^{LV}, Q^{MV}, and Q^{LMV} for $\lambda = 0.1$.

Alternatives	$Q^{\mathrm{V}}_{\lambda=0.1}$ (31)		$Q^{\mathrm{LV}}_{\lambda=0.1}$ (36)		$Q^{\mathrm{MV}}_{\lambda=0.5}$ (32)		$Q^{\mathrm{LMV}}_{\lambda=0.5}$ (37)	
A_1	0.8197	[4]	0.6999	[5]	0.6101	[3]	1.0014	[2]
A_2	0.7778	[3]	0.5124	[2]	0.4981	[2]	1.1008	[3]
A_3	**0.3510**	[**1**]	**0.3723**	[**1**]	0.6316	[4]	1.2093	[4]
A_4	0.6082	[2]	0.5254	[3]	0.7812	[5]	1.3050	[5]
A_5	0.9581	[5]	0.6489	[4]	**0.4313**	[**1**]	**0.9753**	[**1**]

$$= \frac{0.2572}{0.6071} = 0.4237 \geq 0.25,$$

$$\frac{Q^{\mathrm{LV}}_{\lambda=0.1}\left(A^{(2)}\right) - Q^{\mathrm{LV}}_{\lambda=0.1}\left(A^{(1)}\right)}{Q^{\mathrm{LV}}_{\lambda=0.1}\left(A^{(5)}\right) - Q^{\mathrm{LV}}_{\lambda=0.1}\left(A^{(1)}\right)}$$

$$= \frac{Q^{\mathrm{LV}}_{\lambda=0.1}\left(A_2\right) - Q^{\mathrm{LV}}_{\lambda=0.1}\left(A_3\right)}{Q^{\mathrm{LV}}_{\lambda=0.1}\left(A_1\right) - Q^{\mathrm{LV}}_{\lambda=0.1}\left(A_3\right)} = \frac{0.5124 - 0.3723}{0.6999 - 0.3723}$$

$$= \frac{0.1401}{0.3276} = \mathbf{0.4277} \geq 0.25,$$

$$\frac{Q^{\mathrm{MV}}_{\lambda=0.1}\left(A^{(2)}\right) - Q^{\mathrm{MV}}_{\lambda=0.1}\left(A^{(1)}\right)}{Q^{\mathrm{MV}}_{\lambda=0.1}\left(A^{(5)}\right) - Q^{\mathrm{MV}}_{\lambda=0.1}\left(A^{(1)}\right)}$$

$$= \frac{Q^{\mathrm{MV}}_{\lambda=0.1}\left(A_2\right) - Q^{\mathrm{MV}}_{\lambda=0.1}\left(A_5\right)}{Q^{\mathrm{MV}}_{\lambda=0.1}\left(A_4\right) - Q^{\mathrm{MV}}_{\lambda=0.1}\left(A_5\right)} = \frac{0.4981 - 0.4313}{0.7812 - 0.4313}$$

$$= \frac{0.0668}{0.3499} = 0.1909 < 0.25,$$

$$\frac{Q^{\mathrm{LMV}}_{\lambda=0.1}\left(A^{(2)}\right) - Q^{\mathrm{LMV}}_{\lambda=0.1}\left(A^{(1)}\right)}{Q^{\mathrm{LMV}}_{\lambda=0.1}\left(A^{(5)}\right) - Q^{\mathrm{LMV}}_{\lambda=0.1}\left(A^{(1)}\right)}$$

$$= \frac{Q^{\mathrm{LMV}}_{\lambda=0.1}\left(A_1\right) - Q^{\mathrm{LMV}}_{\lambda=0.1}\left(A_5\right)}{Q^{\mathrm{LMV}}_{\lambda=0.1}\left(A_4\right) - Q^{\mathrm{LMV}}_{\lambda=0.1}\left(A_5\right)} = \frac{1.0014 - 0.9753}{1.3050 - 0.9753}$$

$$= \frac{0.0261}{0.3297} = 0.0792 < 0.25; \tag{51}$$

for $\lambda = 0.9$,

$$\frac{Q^{\mathrm{V}}_{\lambda=0.9}\left(A^{(2)}\right) - Q^{\mathrm{V}}_{\lambda=0.9}\left(A^{(1)}\right)}{Q^{\mathrm{V}}_{\lambda=0.9}\left(A^{(5)}\right) - Q^{\mathrm{V}}_{\lambda=0.9}\left(A^{(1)}\right)}$$

$$= \frac{Q^{\mathrm{V}}_{\lambda=0.9}\left(A_4\right) - Q^{\mathrm{V}}_{\lambda=0.9}\left(A_3\right)}{Q^{\mathrm{V}}_{\lambda=0.9}\left(A_5\right) - Q^{\mathrm{V}}_{\lambda=0.9}\left(A_3\right)} = \frac{0.4934 - 0.3756}{0.8395 - 0.3756}$$

$$= \frac{0.1178}{0.4639} = 0.2539 \geq 0.25,$$

$$\frac{Q^{\mathrm{LV}}_{\lambda=0.9}\left(A^{(2)}\right) - Q^{\mathrm{LV}}_{\lambda=0.9}\left(A^{(1)}\right)}{Q^{\mathrm{LV}}_{\lambda=0.9}\left(A^{(5)}\right) - Q^{\mathrm{LV}}_{\lambda=0.9}\left(A^{(1)}\right)}$$

$$= \frac{Q^{\mathrm{LV}}_{\lambda=0.9}\left(A_4\right) - Q^{\mathrm{LV}}_{\lambda=0.9}\left(A_3\right)}{Q^{\mathrm{LV}}_{\lambda=0.9}\left(A_5\right) - Q^{\mathrm{LV}}_{\lambda=0.9}\left(A_3\right)} = \frac{0.9106 - 0.7603}{1.1948 - 0.7603}$$

$$= \frac{0.1503}{0.4345} = \mathbf{0.3459} \geq 0.25,$$

TABLE 13: Ranking of alternatives with respect to values of Q^{V}, $Q^{\mathrm{L+V}}$, Q^{MV}, and Q^{LMV} for $\lambda = 0.5$.

Alternatives	$Q^{\mathrm{V}}_{\lambda=0.5}$ (31)		$Q^{\mathrm{LV}}_{\lambda=0.5}$ (36)		$Q^{\mathrm{MV}}_{\lambda=0.5}$ (32)		$Q^{\mathrm{LMV}}_{\lambda=0.5}$ (37)	
A_1	0.7228	[3]	0.9060	[4]	0.6064	[3]	1.0735	[2]
A_2	0.7783	[4]	0.7753	[3]	0.6229	[4]	1.1021	[3]
A_3	**0.3633**	**[1]**	**0.5663**	**[1]**	**0.5192**	**[1]**	**1.0313**	**[1]**
A_4	0.5508	[2]	0.7180	[2]	0.6469	[5]	1.1511	[5]
A_5	0.8988	[5]	0.9219	[5]	0.6061	[2]	1.1031	[4]

TABLE 14: Ranking of alternatives with respect to values of Q^{V}, Q^{LV}, Q^{MV}, and Q^{LMV} for $\lambda = 0.9$.

Alternatives	$Q^{\mathrm{V}}_{\lambda=0.9}$ (31)		$Q^{\mathrm{LV}}_{\lambda=0.9}$ (36)		$Q^{\mathrm{MV}}_{\lambda=0.9}$ (32)		$Q^{\mathrm{LMV}}_{\lambda=0.9}$ (37)	
A_1	0.6260	[3]	1.1121	[4]	0.6027	[3]	1.1456	[4]
A_2	0.7788	[4]	1.0381	[3]	0.7477	[4]	1.1034	[3]
A_3	**0.3756**	**[1]**	**0.7603**	**[1]**	**0.4067**	**[1]**	**0.8533**	**[1]**
A_4	0.4934	[2]	0.9106	[2]	0.5126	[2]	0.9972	[2]
A_5	0.8395	[5]	1.1948	[5]	0.7809	[5]	1.2310	[5]

TABLE 15: Ranking of alternatives with respect to average values of $\overline{Q}^{\mathrm{V}}$, $\overline{Q}^{\mathrm{LV}}$, $\overline{Q}^{\mathrm{MV}}$, and $\overline{Q}^{\mathrm{LMV}}$.

Alternatives	$\overline{Q}^{\mathrm{V}}$		$\overline{Q}^{\mathrm{LV}}$		$\overline{Q}^{\mathrm{MV}}$		$\overline{Q}^{\mathrm{LMV}}$	
A_1	0.7228	[3]	0.9060	[4]	0.6064	[3]	1.0735	[2]
A_2	0.7783	[4]	0.7753	[3]	0.6229	[4]	1.1021	[3]
A_3	**0.3633**	[1]	**0.5663**	[1]	**0.5192**	[1]	**1.0313**	[1]
A_4	0.5508	[2]	0.7180	[2]	0.6469	[5]	1.1511	[5]
A_5	0.8988	[5]	0.9219	[5]	0.6061	[2]	1.1031	[4]

TABLE 16: Final ranking.

	$\overline{Q}^{\mathrm{V}}$	$\overline{Q}^{\mathrm{LV}}$	$\overline{Q}^{\mathrm{MV}}$	$\overline{Q}^{\mathrm{LMV}}$	Q^{TV}	Q^{TMV}
A_1	3	4	3	2	5	4
A_2	4	3	4	3	**1**	3
A_3	**1**	**1**	**1**	**1**	2	**1**
A_4	2	2	5	5	4	2
A_5	5	5	2	4	3	5

TABLE 17: Kendall rank correlation between different methods.

	Q^{V}	Q^{LV}	Q^{MV}	Q^{LMV}	Q^{TV}	Q^{TMV}
Q^{V}	1.0	**0.8**	0.0	0.4	0.0	**0.8**
Q^{LV}	X	1.0	−0.2	0.2	0.2	1.0
Q^{MV}	X	X	1.0	0.6	0.2	−0.2
Q^{LMV}	X	X	X	1.0	0.2	0.2
Q^{TV}	X	X	X	X	1.0	0.6
Q^{TMV}	X	X	X	X	X	1.0

$$\begin{aligned}
&\frac{Q^{\mathrm{MV}}_{\lambda=0.9}\left(A^{(2)}\right) - Q^{\mathrm{MV}}_{\lambda=0.9}\left(A^{(1)}\right)}{Q^{\mathrm{MV}}_{\lambda=0.9}\left(A^{(2)}\right) - Q^{\mathrm{MV}}_{\lambda=0.9}\left(A^{(1)}\right)} \\
&\quad = \frac{Q^{\mathrm{MV}}_{\lambda=0.9}\left(A_4\right) - Q^{\mathrm{MV}}_{\lambda=0.9}\left(A_3\right)}{Q^{\mathrm{MV}}_{\lambda=0.9}\left(A_5\right) - Q^{\mathrm{MV}}_{\lambda=0.9}\left(A_3\right)} = \frac{0.5126 - 0.4067}{0.7809 - 0.4067} \\
&\quad = \frac{0.1059}{0.3742} = 0.2830 \geq 0.25, \\
&\frac{Q^{\mathrm{LMV}}_{\lambda=0.9}\left(A^{(2)}\right) - Q^{\mathrm{LMV}}_{\lambda=0.9}\left(A^{(1)}\right)}{Q^{\mathrm{LMV}}_{\lambda=0.9}\left(A^{(5)}\right) - Q^{\mathrm{LMV}}_{\lambda=0.9}\left(A^{(1)}\right)} \\
&\quad = \frac{Q^{\mathrm{LMV}}_{\lambda=0.9}\left(A_4\right) - Q^{\mathrm{LMV}}_{\lambda=0.9}\left(A_3\right)}{Q^{\mathrm{LMV}}_{\lambda=0.9}\left(A_5\right) - Q^{\mathrm{LMV}}_{\lambda=0.9}\left(A_3\right)} = \frac{0.9972 - 0.8533}{1.2310 - 0.8533} \\
&\quad = \frac{0.1439}{0.3777} = 0.3810 \geq 0.25.
\end{aligned} \tag{52}$$

We observe that the measures Q^{TV} and Q^{TMV} do not satisfy condition (**C1**), and significant acceptable advantage is obtained by the measure Q^{LV} for all values of λ. On the other hand, it can be observed that the measures Q^{MV} and Q^{LMV} are sensitive to the values of λ. When $\lambda = 0.1$, the measures Q^{MV} and Q^{LMV} do not satisfy condition (**C1**); that is, they do not have the acceptable advantage and when $\lambda = 0.5$ the measure Q^{MV} has the high acceptable advantage (0.6805). Looking at Tables 12–14, we observe sensitivity of the measures Q^{MV} and Q^{LMV} to the values of λ. When $\lambda = 0.5$ and $\lambda = 0.9$ these measures select A_3 as the best alternative, while when $\lambda = 0.1$ they select A_5 as the best alternative.

Checking condition (**C2**) (acceptable stability), as can be seen from Table 11, this condition is satisfied; that is, A_3 is ranked as the best alternative by measures S and R.

7. Conclusions

Personnel selection is the process of choosing individuals who match the qualifications required to perform a defined job in the best possible way. Due to its characteristics and capabilities, the fuzzy VIKOR method has been widely studied and applied in personnel selection problem in recent years. The fuzzy VIKOR method focuses on ranking and selecting from a set of alternatives in a fuzzy environment. The fuzzy VIKOR method is based on the aggregating fuzzy measure Q that represents distance of an alternative to the ideal solution. In this research, we combined modified fuzzy VIKOR and worst-case approaches to develop a more accurate personnel selection methodology. For an illustrative example, proposed model is conducted on an empirical personnel selection process. In general, according to the results of this study, fuzzy VIKOR is a method which can offer suitable alternative. But when the number of criteria is increased, the process of personnel selection will be very complicated. In comparison to fuzzy VIKOR technique, modified fuzzy VIKOR is easy to handle and more quick method in the process of personnel selection. In addition, the results showed very good agreement between fuzzy VIKOR and modified fuzzy VIKOR methods. The final ranking obtained by the proposed modification of fuzzy VIKOR approach was close in accordance with the ranking obtained by the fuzzy VIKOR method. This indicates the usefulness of the proposed modification.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Information Retrieval and Graph Analysis Approaches for Book Recommendation

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A combination of multiple information retrieval approaches is proposed for the purpose of book recommendation. In this paper, book recommendation is based on complex user's query. We used different theoretical retrieval models: probabilistic as InL2 (Divergence from Randomness model) and language model and tested their interpolated combination. Graph analysis algorithms such as PageRank have been successful in Web environments. We consider the application of this algorithm in a new retrieval approach to related document network comprised of social links. We called Directed Graph of Documents (DGD) a network constructed with documents and social information provided from each one of them. Specifically, this work tackles the problem of book recommendation in the context of INEX (Initiative for the Evaluation of XML retrieval) Social Book Search track. A series of reranking experiments demonstrate that combining retrieval models yields significant improvements in terms of standard ranked retrieval metrics. These results extend the applicability of link analysis algorithms to different environments.

1. Introduction

In recent years, document retrieval and recommendation have become more and more popular in many Web 2.0 applications where user can request documents. There has been much work done both in the industry and academia on developing new approaches to improve the performance of retrieval and recommendation systems over the last decade. The interest in this area still remains high to help users to deal with information overload and provide recommendation or retrieval content (books, restaurants, movies, academic publications, etc.). Moreover, some of the vendors have incorporated recommendation capabilities into their commerce services, for example, Amazon in book recommendation.

Existing document retrieval approaches need to be improved to satisfy user's information needs. Most systems use classic information retrieval models, such as language models or probabilistic models. Language models have been applied with a high degree of success in information retrieval applications [1–3]. This was first introduced by Ponte and Croft in [4]. They proposed a method to score documents, called *query likelihood*. It consists of two steps: estimate a language model for each document and then rank documents according to the likelihood scores resulting from the estimated language model. Markov Random Field model was proposed by Metzler and Croft in [5]; it considers query term proximity in documents by estimating term dependencies in the context of language modeling approach. From the existing probabilistic models, InL2 a Divergence from Randomness-based model was proposed by Amati and Van Rijsbergen in [6]. It measures the global informativeness of the term in the document collection. It is based on the idea that "*the more the term occurrences diverge from random throughout the collection, the more informative the term is.*" The limit of such models is that the distance between query terms in documents is not considered.

In this paper, we present an approach that combines probabilistic and language models to improve the retrieval performances and show that the two models combined act much better in the context of book recommendation.

In recent years, an important innovation in information retrieval appeared which consists of algorithms developed to exploit the relationships between documents. One of the important algorithm is Google's PageRank [7]. It has been successful in Web environments, where the relationships are provided with the existing hyperlinks into documents. We present a new approach for document retrieval based on graph analysis and exploit the PageRank algorithm for ranking documents with respect to a user's query. In the absence of manually created hyperlinks, we use social information to create the Directed Graph of Documents (DGD) and argue that it can be treated in the same manner as hyperlink graphs. Experiments show that incorporating graph analysis algorithms in document retrieval improves the performances in term of the standard ranked retrieval metrics.

Our work focuses on search in the book recommendation domain, in the context of INEX Social Book Search track. The document collection contains Amazon/LibraryThing book descriptions and the queries, called topics, are extracted from the LibraryThing discussion forums.

In the rest of the paper, we presented a summary of related work in document retrieval and recommender systems. Then, we describe briefly the used retrieval models and show the combination method. In Section 5, we illustrate the graph modeling method followed by the different experiments and results.

2. Related Work

This work is first related to the area of document retrieval models, more specially language models and probabilistic models. The unigram language models are the most used for ad hoc information retrieval work; several researchers explored the use of language modeling that captures higher order dependencies between terms. Bouchard and Nie in [9] have showed significant improvements of retrieval effectiveness with a new statistical language model for the query based on three different ways: completing the query by terms in the user's domain of interest, reordering the retrieval results, or expanding the query using lexical relations extracted from the user's domain of interest.

Divergence from Randomness (DFR) is one of several probabilistic models that we have used in our work. Abolhassani and Fuhr have investigated several possibilities for applying Amati's DFR model [6] for content-only search in XML documents [10].

This work also relates to the category of graph based document retrieval. There has been increasing use of techniques based on graphs constructed by implicit relationships between documents. Kurland and Lee performed structural reranking based on centrality measures in graph of documents which has been generated using relationships between documents based on language models [11]. In [12], Lin demonstrates the possibility to exploit document networks defined by automatically generated content-similarity links for document retrieval in the absence of explicit hyperlinks. He integrates the PageRank scores with standard retrieval score and shows a significant improvement in ranked retrieval performance. His work was focused on search in the biomedical domain, in the context of PubMed search engine.

3. INEX Social Book Search Track and Test Collection

SBS task (http://social-book-search.humanities.uva.nl/) aims to evaluate the value of professional and user's metadata for book search on the Web. The main goal is to exploit search techniques to deal with complex information needs and complex information sources that include user profiles, personal catalogs, and book descriptions.

The SBS task builds on a collection of 2.8 million book description crawled by the University of Duisburg-Essen from Amazon (http://www.amazon.com/) [13] and enriched with content from LibraryThing (http://www.librarything.com/). Each book is identified by an ISBN and is an XML file. It contains content information like title information, Dewey Decimal Classification (DDC) code (for 61% of the books), category, Amazon product description, and so forth. Amazon records contain also social information generated by users like tags, reviews, and ratings. For each book, Amazon suggests a set of "Similar Products" which represents a result of computed similarity based on content information and user behavior (purchases, likes, reviews, etc.) [14].

SBS task provides a set of queries called topics each year where users describe what they are looking for (books for a particular genre, books of particular authors, similar books to those that have been already read, etc.). These requests for recommendations are natural expressions of information needs for a large collection of online book records. The topics are crawled from LibraryThing discussion forums.

The topic set consists of 680 topics and 208 topics in 2014 and 2015, respectively. Each topic has a narrative description of the information needs. The topic set of 2015 is a subset of that of 2014. Each topic consists of a set of fields. In this contribution we use *title*, *mediated query* (query description), and *narrative* fields. An example of topic is illustrated in Figure 1.

4. Retrieval Models

This section presents brief description and combination method of retrieval models used for book recommendation.

4.1. InL2 of Divergence from Randomness. We used InL2, Inverse Document Frequency model with Laplace aftereffect and Normalization 2. This model has been used with success in different works [15–18]. InL2 is a DFR-based model (Divergence from Randomness) based on the Geometric distribution and Laplace law of succession. The DFR models are based on this idea: "The more the divergence of the within-document term-frequency from its frequency within the collection, the more the information carried by the word t in the document d" [19]. For this model, the relevance score of a document D for a query Q is given by

$$\operatorname{score}(Q, D) = \sum_{t \in Q} \mathrm{qtw} \cdot \frac{1}{\mathrm{tfn} + 1} \left(\mathrm{tfn} \cdot \log \frac{N + 1}{n_t + 0.5} \right), \quad (1)$$

where qtw is the query term weight given by $\mathrm{qtf}/\mathrm{qtf}_{\max}$; qtf is the query term frequency; $\mathrm{qtf}_{\max}$ is the maximum query

```
<topic id="1116">
   <title>Which LISP?</title>
   <mediated_query>introduction book to Lisp</mediated_query>
   <group>Purely Programmers</group>
   <narrative>It'll be time for me to shake things up and learn a new
        language soon. I had started on Erlang a while back and getting
        back to it might be fun. But I'm starting to lean toward Lisp--
        probably Common Lisp rather than Scheme. Anyone care to
        a good first Lisp book? Would I be crazy to hope that there's
        one out there with an emphasis on using Lisp in a web
        and/or system administration context? Not that I'm unhappy with
        PHP and Perl, but the best way for me to find the time to learn
        new language is to use it for my work... </narrative>
</topic>
```

Figure 1: An example of topic from SBS topics set composed with multiple fields to describe user's need.

term frequency among the query terms. N is the number of documents in the whole collection and n_t is the number of documents containing t. tfn corresponds to the weighted sum of normalized term frequencies tf_f for each field f, known as *Normalization 2* and given by

$$\mathrm{tfn} = \mathrm{tf} \cdot \log\left(1 + c \cdot \frac{\mathrm{avg\_}l}{l}\right) \quad (c > 0), \tag{2}$$

where tf is the frequency of term t in the document D; l is the length of the document in tokens and avg_l is the average length of all documents; c is a hyperparameter that controls the normalization applied to the term frequency with respect to the document length.

4.2. Sequential Dependence Model of Markov Random Field. Language models are largely used in document retrieval search for book recommendation [16, 20]. Metzler and Croft's Markov Random Field (MRF) model [21, 22] integrates multiword phrases in the query. Specifically, we used the Sequential Dependence Model (SDM), which is a special case of MRF. In this model cooccurrence of query terms is taken into consideration. SDM builds upon this idea by considering combinations of query terms with proximity constraints which are single term features (standard unigram language model features, f_T), exact phrase features (words appearing in sequence, f_O), and unordered window features (require words to be close together, but not necessarily in an exact sequence order, f_U).

Finally, documents are ranked according to the following scoring function:

$$\begin{aligned}\mathrm{SDM}(Q, D) = {} & \lambda_T \sum_{q \in Q} f_T(q, D) \\ & + \lambda_O \sum_{i=1}^{|Q|-1} f_O(q_i, q_i + 1, D) \\ & + \lambda_U \sum_{i=1}^{|Q|-1} f_U(q_i, q_i + 1, D),\end{aligned} \tag{3}$$

where feature weights are set based on the author's recommendation ($\lambda_T = 0.85$, $\lambda_O = 0.1$, $\lambda_U = 0.05$) in [20]. f_T, f_O, and f_U are the log maximum likelihood estimates of query terms in document D as shown in Table 1, computed over the target collection using a Dirichlet smoothing. We applied this model to the queries using Indri (http://www.lemurproject.org/indri/) Query Language (http://www.lemurproject.org/lemur/IndriQueryLanguage .php).

4.3. Combining Search Systems. The use of different retrieval systems retrieves different sets of documents. Combining the output of many search systems, in contrast to using just a single retrieval technique, can improve the retrieval effectiveness as shown by Belkin et al. in [23] where the authors have combined the results of probabilistic and vector space models. In our work, we combined the results of InL2 model and SDM model. The retrieval models use different weighting schemes; therefore we should normalize the scores. We used the maximum and minimum scores according to Lee's formula [24] as follows:

$$\mathrm{normalizedScore} = \frac{\mathrm{oldScore} - \mathrm{minScore}}{\mathrm{maxScore} - \mathrm{minScore}}. \tag{4}$$

It has been shown in [16] that InL2 and SDM models have different levels of retrieval effectiveness; thus it is necessary to weight individual model scores depending on their overall performance. We used an interpolation parameter (α) that we have varied to get the best interpolation that provides better retrieval effectiveness.

5. Graph Modeling

We have studied the INEX SBS collection to link documents. In [25], the authors have used PubMed collection and exploited networks defined by automatically generated content-similarity links for document retrieval. In our case, we exploited a special type of similarity based on several factors. This similarity is provided by Amazon and corresponds to "Similar Products" given generally for each visited book.

Table 1: Language modeling-based unigram and term weighting functions. Here, $tf_{e,D}$ is the number of times term e matches in document D, $cf_{e,D}$ is the number of times term e matches in the entire collection, $|D|$ is the length of document D, and $|C|$ is the size of the collection. Finaly, μ is a weighting function hyperparameter that is set to 2500.

Weighting	Description
$f_T(q_i, D) = \log\left[\dfrac{tf_{q_i,D} + \mu cf_{q_i}/\|C\|}{\|D\| + \mu}\right]$	Weight of unigram q_i in document D.
$f_O(q_i, q_{i+1}, D) = \log\left[\dfrac{tf_{\#1(q_i,q_{i+1}),D} + \mu cf_{\#1(q_i,q_{i+1})}/\|C\|}{\|D\| + \mu}\right]$	Weight of exact phrase "$q_i \quad q_{i+1}$" in document D.
$f_O(q_i, q_{i+1}, D) = \log\left[\dfrac{tf_{\#uw8(q_i,q_{i+1}),D} + \mu cf_{\#uw8(q_i,q_{i+1})}/\|C\|}{\|D\| + \mu}\right]$	Weight of unordered window "$q_i \quad q_{i+1}$" (span = 8) in document D.

(1) $D_{\text{init}} \leftarrow$ Retrieving Documents for each $t_i \in T$
(2) **for** each $D_{t_i} \in D_{\text{init}}$ **do**
(3) $D_{\text{StartingNodes}} \leftarrow$ first β documents $\in D_{t_i}$
(4) **for** each StartingNode **in** $D_{\text{StartingNodes}}$ **do**
(5) $D_{\text{graph}} \leftarrow D_{\text{graph}}$ + neighbors(StartingNode, DGD)
(6) $D_{\text{SPnodes}} \leftarrow$ **all** $D \in$ ShortestPath(StartingNode, $D_{\text{StartingNodes}}$, DGD)
(7) $D_{\text{graph}} \leftarrow D_{\text{graph}} + D_{\text{SPnodes}}$
(8) Delete all duplications from D_{graph}
(9) $D_{\text{final}} \leftarrow D_{\text{final}} + (D_{t_i} + D_{\text{graph}})$
(10) Delete all duplications from D_{final}
(11) Rerank D_{final}

Algorithm 1: Retrieving based on DGD feedback.

Amazon suggests books in "Similar Products" according to there similarity to the consulted book. The degree of similarity is relative to user's social information like clicks or purchases and content based information like book attributes (book description, book title, etc.). The exact formula that combines social and content based information to compute similarity is not delivered by Amazon.

To perform data modeling into DGD, we extracted the "Similar Products" links between documents. The constructed DGD will be used to enrich returned results by the retrieval models; that is, we use the graph structure in the same spirit of pseudorelevance-feedback algorithms. Our method can potentially serve to greatly enhance the retrieval performances.

In this section we use some fixed notations. The collection of documents is denoted by C. In C, each document d has a unique ID. The set of queries called topics is denoted by T, the set $D_{\text{init}} \subset C$ refers to the documents returned by the initial retrieval model. StartingNode indicates document from D_{init} which is used as input to graph processing algorithms in the DGD. The set of documents present in the graph is denoted by S. D_{t_i} indicates the documents retrieved for topic $t_i \in T$.

Each node in the DGD represents document (Amazon description of book) and has set of properties:

(i) ID: book's ISBN;

(ii) content: book description that includes many other properties (title, product description, author(s), users' tags, content of reviews, etc.);

(iii) MeanRating: average of ratings attributed to the book;

(iv) PR: value of book PageRank.

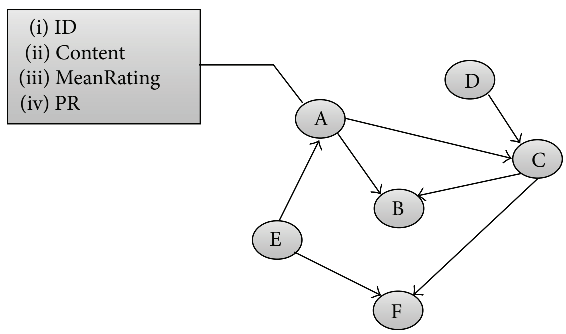

Figure 2: Example of Directed Graph of Documents.

Nodes are connected with directed links; given nodes $\{A, B\} \in S$, if A points to B, B is suggested as Similar Product to A. In Figure 2, we show an example of DGD, network of documents. The DGD network contains 1.645.355 nodes (89.86% of nodes are in the collection and the rest do not belong to it) and 6.582.258 relationships.

5.1. Our Approach. The DGD network contains useful information about documents that can be exploited for document retrieval. Our approach is based first on results of traditional retrieval approach and then on the DGD network to find other documents. The idea is to suppose that the suggestions given by Amazon can be relevant to the user queries.

We introduce the algorithm called "retrieving based on DGD feedback." Algorithm 1 takes the following as inputs: D_{init} returned list of documents for each topic by the

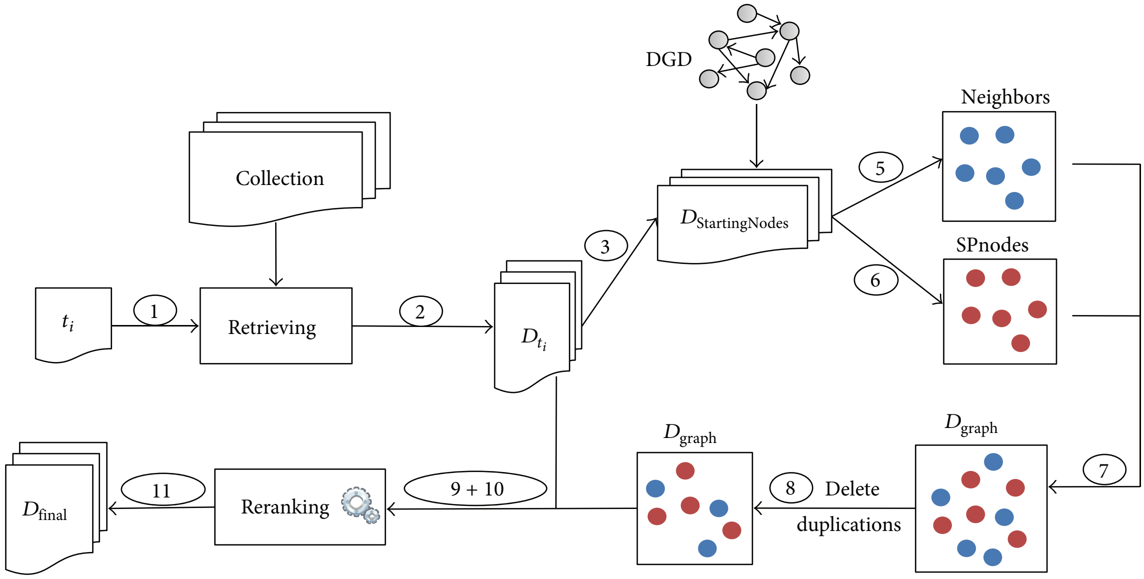

Figure 3: Architecture of book retrieval approach based on DGD feedback.

retrieval techniques described in Section 3, DGD network, and parameter β which is the number of the top selected StartingNode from D_{init} denoted by $D_{\text{StartingNodes}}$. We fixed β to 100 (10% of the returned list for each topic). The algorithm returns list of recommendations for each topic denoted by "D_{final}". It processes topic by topic and extracts the list of all neighbors for each StartingNode. It performs mutual Shortest Paths computation between all selected StartingNode in DGD. The two lists (neighbors and nodes in computed Shortest Paths) are concatenated; after that all duplicated nodes are deleted. The set of documents in returned list is denoted by "D_{graph}". A second concatenation is performed between initial list of documents and D_{graph} (all duplications are deleted) in new final list of retrieved documents; "D_{final}" reranked using different reranking schemes.

Figure 3 shows the architecture of the document retrieval approach based on DGD feedback. The numbers on arrows represent instructions in Algorithm 1.

6. Experiments and Results

In this section, we describe the experimental setup we used for our experiments. Furthermore, we present the different reranking schemes used in previously defined approaches.

6.1. Experiments Setup. For our experiments, we used different tools that implement retrieval models and handle the graph processing. First, we used Terrier (Terabyte Retriever) (http://terrier.org/) Information Retrieval framework developed at the University of Glasgow [26–28]. Terrier is a modular platform for rapid development of large-scale IR applications. It provides indexing and retrieval functionalities. It is based on DFR framework and we used it to deploy InL2 model described in Section 4.1. Further information about Terrier can be found at http://ir.dcs.gla.ac.uk/terrier.

A preprocessing step was performed to convert INEX SBS corpus into Trec Collection Format (http://lab.hypotheses.org/1129), by considering that the content of all tags in each XML file is important for indexing; therefore the whole XML file was transformed on one document identified by its ISBN. Thus, we just need two tags instead of all tags in XML, the ISBN and the whole content (named text).

Secondly, *Indri* (http://www.lemurproject.org/indri/), *Lemur Toolkit for Language Modeling and Information Retrieval* was used to carry out a language model (SDM) described in Section 4.2. Indri is a framework that provides state-of-the-art text search methods and a rich structured query language for big collections (up to 50 million documents). It is a part of the Lemur project and developed by researchers from UMass and Carnegie Mellon University. We used Porter stemmer and performed Bayesian smoothing with Dirichlet priors (Dirichlet prior $\mu = 1500$).

In Section 5.1, we have described our approach based on DGD which includes graph processing. We used NetworkX (https://networkx.github.io/) tool of Python to perform shortest path computing, neighborhood extraction, and PageRank calculation.

To evaluate the results of retrieval systems, several measurements have been used for SBS task: Discounted Cumulative Gain (nDCG), the most popular measure in IR [29], Mean Average Precision (MAP) which calculates the mean of average precisions over a set of queries, and other measures: Recip Rank and Precision at the rank 10 (P@10).

6.2. Reranking Schemes. In this paper, we have proposed two approaches. The first (see Section 4.3) consists of merging the results of two different information retrieval models which are the language model (SDM) and DFR model (InL2). For topic t_i, each of the models gives 1000 documents and each retrieved document has an associated score. The linear combination method uses the following formula to calculate

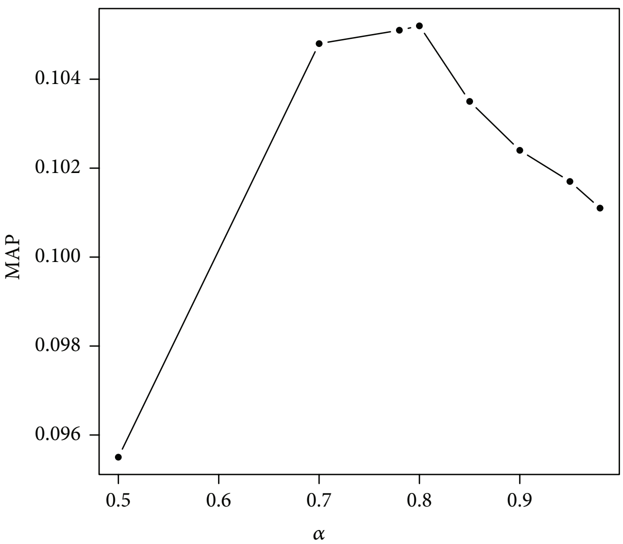

Figure 4: MAP distribution for INEX SBS 2014 when varying the interpolation parameter α.

final score for each retrieved document d by SDM and InL2 models:

$$\text{final}_{\text{score}(d,t_i)} = \alpha \cdot \text{score}_{\text{InL2}}\left(d,t_i\right) + (1-\alpha) \cdot \text{score}_{\text{SDM}}\left(d,t_i\right), \tag{5}$$

where $\text{score}_{\text{InL2}}(d,t_i)$ and $\text{score}_{\text{SDM}}(d,t_i)$ are normalized scores. α is the interpolation parameter set up at 0.8 after several tests on topics 2014, according to the MAP measure shown in Figure 4.

The second approach (described in Section 5.1) uses the DGD constructed from the "Similar Products" information. The document set returned by the retrieval model are fused to the documents in neighbors set and Shortest Path results. We tested different reranking methods that combine the retrieval model scores and other scores based on social information. For each document in the resulting list, we calculated the following scores:

(i) *PageRank*, computed using NetworkX tool: it is a well-known algorithm that exploits link structure to score the importance of nodes in a graph. Usually, it has been used for hyperlink graphs such as the Web [30].

(ii) *MeanRatings*, information generated by users: it represents the mean of all ratings attributed by users for a book.

The computed scores were normalized using this formula: normalizedScore = oldScore/maxScore. After that, to combine the results of retrieval system and each of normalized scores, an intuitive solution is to weight the retrieval model scores with the previously described scores (normalized PageRank and MeanRatings). However, this would favor documents with high PageRank and MeanRatings scores even though their content is much less related to the topics.

6.3. Results. In this section, we discuss the results we achieved by using the InL2 retrieval model, its combination to the SDM model, and retrieval system proposed in our approach that uses the graph structure DGD.

We used two topic sets provided by INEX SBS task in 2014 (680 topics) and 2015 (208 topics). The systems retrieve 1000 documents per topic. The experimental results, which describe the performance of the different retrieval systems on INEX document collection, are shown in Table 2.

As illustrated in Table 2, the system that combines probabilistic model InL2 and the language model SDM (InL2_SDM) achieves a significant improvement comparing to InL2 model (baseline). The two systems do not provide similar level of retrieval effectiveness (as proved in [16]). The results of run InL2_DDG_PR using the 2015 topic set confirm that incorporating PageRank scores using our approach based on DGD network improves ranked retrieval performance but decreases the baseline performances when using the 2014 topic set. The run that uses the MeanRatings property (InL2_DGD_MnRtg) to rerank retrieved documents is the lowest performer in terms of all measurements for 2014 topic set. That means that ratings given by users do not help to improve the reranking performances for 2014 topic set.

Notice that 2015 topic set contains a subset of 2014 topic set. We can clearly observe the difference between results of systems using the two topic sets. We think that the main reason is the evaluation processes that are not the same. Where analysing the qrels of common topics between 2014 and 2015 sets, we found that relevancy values are not the same in most cases. More details on the evaluation processes used in 2014 and 2015 can be found in [31] and http://social-book-search.humanities.uva.nl/#/suggestion.

Nevertheless, the depicted results confirm that we are starting with competitive baseline, the improvements contributed by combining the retrieval systems' outputs and social link analysis are indeed meaningful.

7. Conclusion and Future Work

This paper proposed and evaluated two approaches of document retrieval in the context of book recommendation. We used the test collection of INEX Social Book Search track and the proposed topics in 2014 and 2015. We presented the first approach that combines the outputs of probabilistic model (InL2) and language model (SDM) using a linear interpolation after normalizing scores of each retrieval system. We have shown a significant improvement of baseline results using this combination.

This paper also proposed a novel approach based on Directed Graph of Documents (DGD). It exploits social link structure to enrich the returned document list by traditional retrieval model (InL2, in our case). We performed a reranking method using PageRank and ratings of each retrieved document.

For future work, we would like to test the proposed approaches in this paper on another test collection which consists of OpenEdition Portal. It is dedicated to electronic resources in the humanities and social sciences. We would like to explore citation links between scientific documents

Table 2: Experimental results. The runs are ranked according to nDCG@10. (∗) denotes significance according to Wilcoxon test [8]. In all cases, all of our tests produced two-sided p value, $\alpha = 0.05$.

		2014 topic set		
Run	nDCG@10	Recip Rank	MAP	P@10
InL2	**0.128**	**0.236**	**0.101**	**0.067**
InL2_SDM	0.136 (+6%*)	0.249 (+5%*)	0.1052 (+4%*)	0.070 (+4%*)
InL2_DGD_PR	0.122 (−4%*)	0.239 (+1%*)	0.090 (−9%*)	0.0695 (+2%*)
InL2_DGD_MnRtg	0.105 (−17%*)	0.192 (−18%*)	0.081 (−18%*)	0.057 (−15%*)
		2015 topic set		
Run	nDCG@10	Recip Rank	MAP	P@10
InL2	**0.063**	**0.147**	**0.046**	**0.044**
InL2_SDM	0.069 (+9%*)	0.166 (+12%*)	0.051 (+10%)	0.050 (+13%*)
InL2_DGD_PR	0.068 (+7%*)	0.157 (+6%*)	0.048 (+4%*)	0.052 (+18%*)
InL2_DGD_MnRtg	0.066 (+4%)	0.148 (+0.6%)	0.042 (−8%)	0.052 (+18%*)

extracted using Kim et al. [32]. Using the traversal algorithms we will develop a new way to retrieve documents. Another interesting extension of this work would be using the learning to rank techniques to automatically adjust the settings of reranking parameters.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Traffic and Driving Simulator Based on Architecture of Interactive Motion

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This study proposes an architecture for an interactive motion-based traffic simulation environment. In order to enhance modeling realism involving actual human beings, the proposed architecture integrates multiple types of simulation, including: (i) motion-based driving simulation, (ii) pedestrian simulation, (iii) motorcycling and bicycling simulation, and (iv) traffic flow simulation. The architecture has been designed to enable the simulation of the entire network; as a result, the actual driver, pedestrian, and bike rider can navigate anywhere in the system. In addition, the background traffic interacts with the actual human beings. This is accomplished by using a hybrid mesomicroscopic traffic flow simulation modeling approach. The mesoscopic traffic flow simulation model loads the results of a user equilibrium traffic assignment solution and propagates the corresponding traffic through the entire system. The microscopic traffic flow simulation model provides background traffic around the vicinities where actual human beings are navigating the system. The two traffic flow simulation models interact continuously to update system conditions based on the interactions between actual humans and the fully simulated entities. Implementation efforts are currently in progress and some preliminary tests of individual components have been conducted. The implementation of the proposed architecture faces significant challenges ranging from multiplatform and multilanguage integration to multievent communication and coordination.

1. Introduction

A vast number of studies have illustrated the potential of driving simulators to analyze actual driver behavior for multiple purposes, such as traffic safety and information provision [1–5]. The history of driving simulators can be traced back to the 1920s, with research for various purposes [6]. In the 1980s, Daimler-Benz [7] developed a high-fidelity driving simulator, encouraging others to develop even better simulators. Several researchers and commercial companies have developed driving simulators ranging from fixed-based simulators to the most advanced motion-based simulators known today. Some of the newest driving simulators include the National Advanced Driving Simulator (NADS), funded by NHTSA and maintained by the University of Iowa [8]; the Driving Environment Simulator (DES), developed by the University of Minnesota [9] in collaboration with AutoSim and Realtime Technologies; the VTI Simulator IV by the Swedish National Road and Transport Research Institute [10]; the University of Leeds driving simulator [11]; DriveSafety driving simulator by the University of Michigan Transportation Research Institute (UMTRI) [12]; the STISIM Drive driving simulator by System Technology Inc.; [13] and the UC-win/Road driving simulator by FORUM8 [14].

The National Advanced Driving Simulator (NADS) Laboratory [8] at the University of Iowa has very advanced driving simulators including NADS-1, NADS-2, and the MiniSim simulator. NADS-1 is an advanced motion-based ground vehicle simulator. NADS-2 is similar to NADS-1 but fixed-based. The MiniSim is a PC-based, high-performance driving simulator that uses the same technology as NADS-1. However, MiniSim can be used at a lower cost than NADS-1 and NADS-2 because it is portable and easy to set up and operate.

The Human Factors Interdisciplinary Research in Simulation and Transportation Program (HumanFIRST) at the University of Minnesota has the Driving Environment Simulator (DES) [9]. DES is an immersive driving simulator that provides high fidelity simulation to generate a realistic presence within the simulated environment. DES measures psychophysiological responses, including brain activity—for example, Evoked Response Potential (ERP). DES also includes highly accurate eye-tracker software. HumanFIRST has a portable, low-cost driving simulator that uses the same technology as DES.

UC-win/Road [14] is a Virtual Reality (VR) environment where the driver can navigate in a three-dimensional (3D) space. The environment, including a traffic simulation and visualization tool, uses ground texture maps and can include 3D building images. The environment also includes traffic generation models to generate traffic on various lanes and roads.

This study proposes an architecture for an interactive motion-based traffic simulation environment. Although the existing driving simulation models provide tremendous capabilities to study driving behavior in a safe and controlled environment, there are multiple aspects of the real-world that can be addressed to significantly enhance modeling realism. The proposed architecture integrates multiple types of simulation, including (i) a motion-based driving simulation; (ii) a pedestrian simulation; (iii) a motorcycling and bicycling simulation; and (iv) a traffic flow simulation. This integration enables the simultaneous and interactive interaction between actual and simulated drivers, pedestrians, and bike riders. In addition, the architecture provides capabilities to simulate the entire network at a reasonable price; in this way, the drivers, pedestrians, and bike riders can navigate anywhere in the system.

To increase modeling realism, the proposed architecture enables actual humans to experience background traffic and the background traffic to be affected by the decisions and behavior of the actual humans navigating the system. To achieve this interaction, the background traffic is modeled using a hybrid mesomicroscopic modeling approach for traffic flow simulation. The mesoscopic traffic flow simulation module of the hybrid model loads the results of a user equilibrium traffic assignment solution and propagates the corresponding traffic throughout the entire system. The microscopic traffic flow simulation model provides background traffic around the vicinities where actual human beings are navigating the system. The two traffic flow simulation models interact continuously to update system conditions, based on the interactions between actual humans and the fully simulated entities. The interaction between actual and background traffic has tremendous implications. For example, in the real-world, an accident, as consequence of a human error, can affect a large portion of the traffic system. These types of scenarios of significant interest for a number of applications cannot be modeled realistically without using the proposed architecture that integrates the driving simulator and the microscopic traffic flow simulator. Such scenario requires capabilities to propagate traffic and represent congestion related phenomena including queue formation and dissipation as well as spillback and spillover. Existing driving simulation models do not provide such capabilities because they do not model background traffic using realistic traffic flow models.

Depending upon the nature of the experiment, a scenario can be designed using a single simulator or any instances of simulators. Some examples for which the proposed system can be used include the following:

(1) The evaluation of driver and pedestrian behavior for traffic safety projects including distracted driving and/or walking and driving and/or walking under the influence of alcohol or drugs [1–5].

(2) The evaluation of multiple mechanisms or technologies designed to assist the driving task and to improve traffic safety. Some of these mechanisms and technologies include crosswalks, flashing lights, infrared sensors to detect pedestrians, distance warning systems, dynamic cruise control, automatic braking systems, and dynamic navigation.

(3) The simultaneous study of the interactions among drivers, pedestrians, and bikers as well as the interactions of them with the infrastructure and the control and information mechanisms and the different technologies used influencing behavior and/or assisting the navigation tasks. The existing literature [15–17] relies on models that do not use actual humans during the experimental part of the analysis.

(4) The training of first responders and emergency personnel. Multiple potential emergency scenarios can be designed and used to provide adequate training in safe and controlled environment. Burke et al. [18] documents the importance of training such personnel. Accidents involving emergency vehicles were analyzed using several sources of information including video data as well as interviews. The results highlighted that drivers' errors were responsible for most of the accidents.

In this study, implementation efforts are currently in progress, and some preliminary tests of individual components have been conducted. The implementation of the proposed architecture faces significant challenges, ranging from multiplatform and multilanguage integration to multievent communication and coordination. To address some of those challenges and achieve the greatest benefits at the lowest cost, state-of-the-art technologies currently are being used to implement the proposed architecture. Some of these technologies include (i) Open Street Maps (OSM) [19]; (ii) Blender [20]; (iii) DynusT© [21]; CORBA; and free SDKs, such as MS Kinect [22] and Ardunio [23]. The proposed architecture is called Networked Motion-Based Interactive PEdestrian and Driving Simulator (n-MIPEDS). Although particular suggestions to implement the proposed architecture are provided

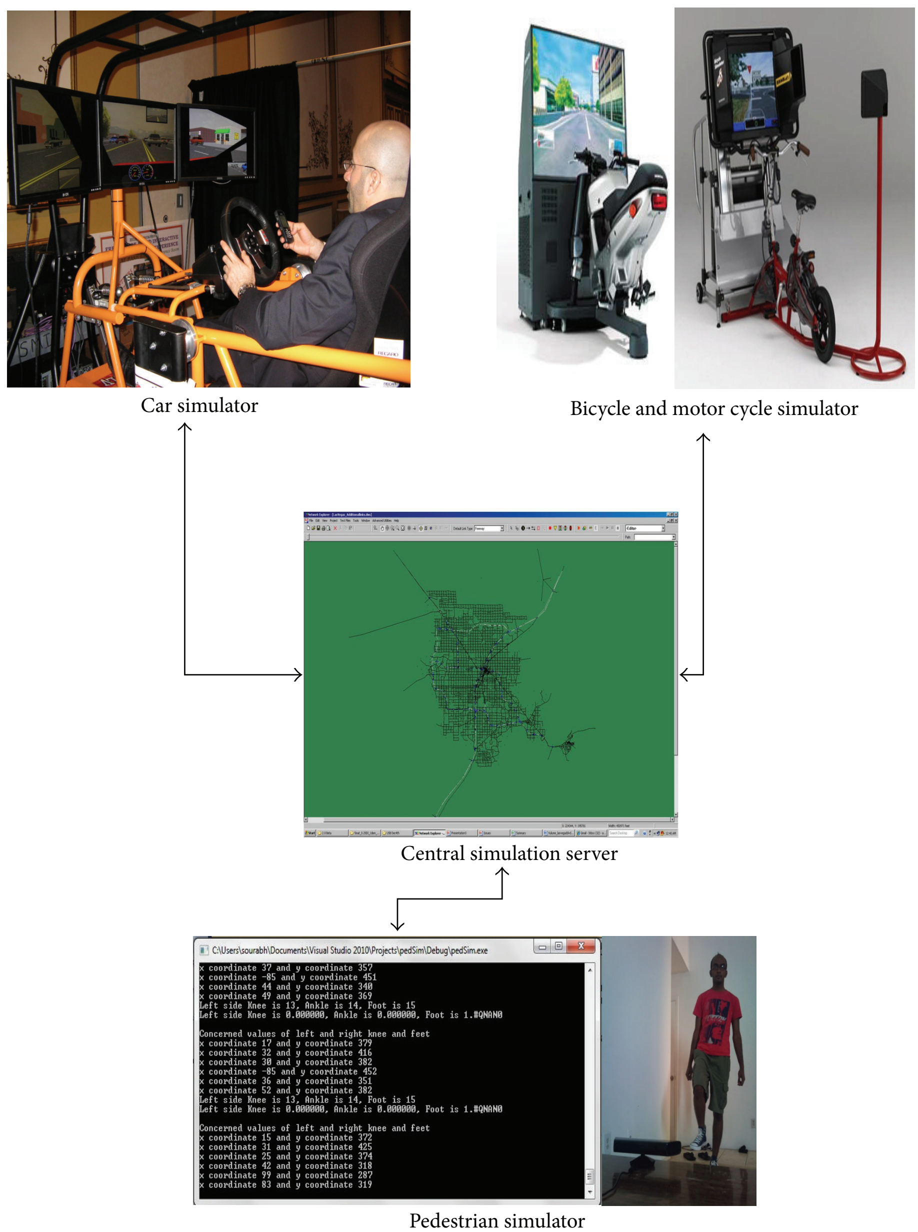

Figure 1: System architecture of n-MIPEDS. (The images for the bicycle and motorcycle simulators are used here for illustrative purposes only. Copyright: Honda.)

in this paper, the conceptual architecture is general and can be implemented using multiple technologies. Appropriate modules can be developed depending on available hardware. In particular, this study uses a SimCraft three-axis motion-based driving simulator.

2. Materials and Methods

The proposed architecture uses a multiplayer framework where each player is connected to the traffic system through a communication network (LAN or internet). The corresponding system architecture diagram and data flow diagram are shown in Figures 1 and 2, respectively. Figure 1 illustrates the following:

(1) *A Car Simulator*. This simulator generates motion and the corresponding forces based on the roadway conditions and the driver's behavior and actions. Hence, the human being driving in the driving simulator experiences a realistic journey and reveals a behavior that is not artificially affected by unrealistic modeling. This driver is termed in this study the virtual driver. In the experimental framework, a SimCraft motion-based driving simulator with 3 Degrees of Freedom (3DoFs) is used.

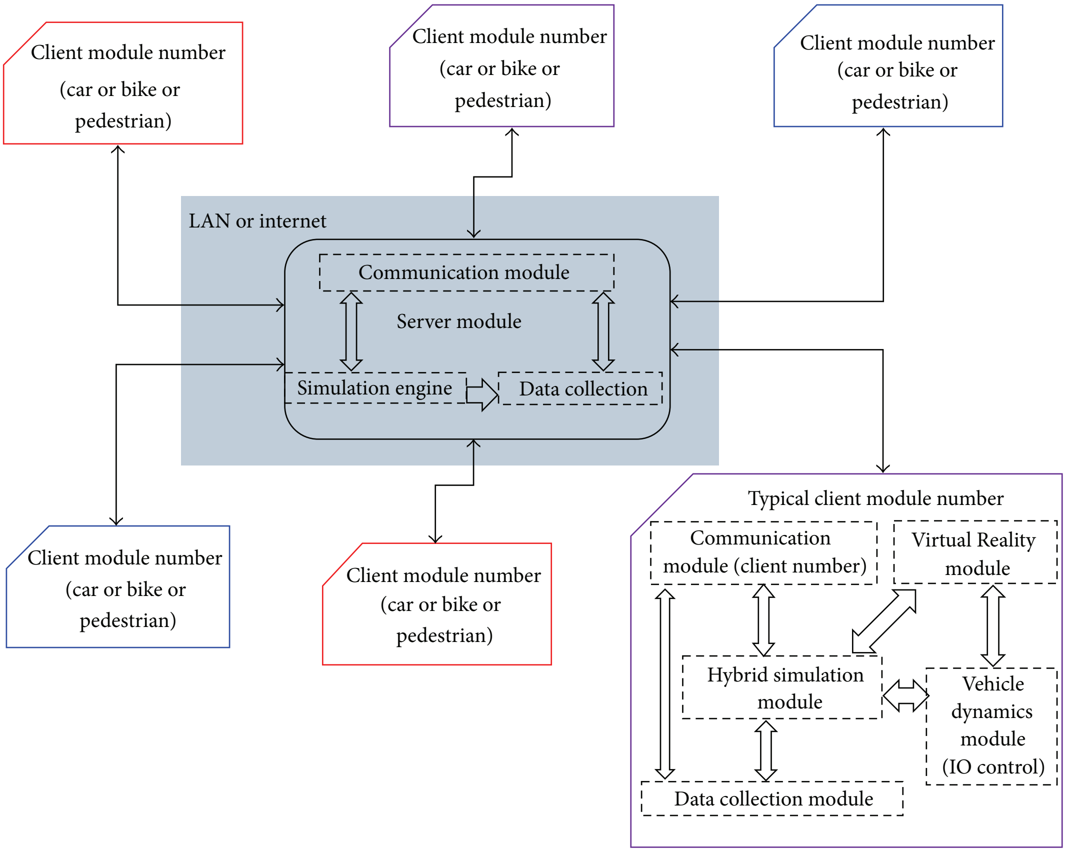

Figure 2: Data flow diagram.

(2) *A Pedestrian Simulator*. This simulator comprises Microsoft Kinect to capture and display the movements of walking human.

(3) *A Bicycle and Motorcycle Simulator*. This is a motion-based simulator with capabilities to simulate a self-powered or fuel-powered bike. It consists of a computer CPU with a graphics card, a Head-Up-Display setup or LCD screen, a motion base, and a joystick.

(4) *A Central Simulation Server*. This server runs simultaneously on parallel CPUs the mesoscopic and microscopic simulations and provides the background traffic to the driving, pedestrian, and bike simulators. It also takes care of the communication and data transfer between the different simulators. The implementation involves a high end supercomputer running Microsoft Windows 7 64-bit edition and networking hardware including a 1000BaseT Gigabit Ethernet as well as the necessary routers and switches to complete the network.

The data flow diagram illustrated in Figure 2 includes a server module and client modules. There are various types of clients to represent different traffic entities such as cars, bikes, or pedestrians. Each client module in turn includes the following modules:

(i) *Hybrid Simulation Module*. This hybrid simulation module is required to provide realistic and consistent traffic around the vicinity of the virtual driver and to capture the consequences of the driver actions on the entire system. It combines a microscopic and a mesoscopic traffic flow simulators. In this module, the actions and location of the virtual driver are directly and continuously incorporated into the microscopic model. The microscopic simulator continuously receives traffic from and sends traffic to the mesoscopic simulator considering the boundary established by the location of the virtual driver.

(ii) *Virtual Reality (VR) Module*. This module creates a simulated world around the vicinity of the virtual driver and provides the associated audio and 3D graphics. It receives information from the hybrid simulation module and provides information to the virtual driver.

(iii) *Vehicle Dynamics Module*. This module generates the motion related information for each of the simulators based on the traffic conditions and the users' actions.

(iv) *Communication Module*. This module enables communication between the server and the client module. It is responsible for synchronizing the transfer of information between the client and the server. For various reasons, the modules proposed in this architecture are being developed using different environments. Hence, the Common Object Request Broker Architecture (CORBA) is to enable interoperability across different language and platforms [24].

(v) *Data Collection Module*. This module collects a vast array of data including drivers' and pedestrians' behavior as well as the associated traffic characteristics.

The server module integrates all the information and it is responsible for tracking the entire system performance using a communication and data collection module and a simulation engine. The simulation engine receives information from all the clients via the communication. That information is stored via the data collection module. Information about system states is also sent to each of the clients using the communication module.

2.1. Roadway Network Geometry. Some simulators such as STISIM Drive [13] only support modeling of corridors without enabling network-level representation. The proposed architecture enables the modeling of generalized networks. Geometric and control characteristics are particularly important for microscopic traffic flow simulation. Data about actual road network geometry for a given city can be obtained from Open Street Maps (OSM) [19] in .xml format. This type of data includes latitude, longitude, street names, intersection details, and horizontal curve information. The OSM data is an open source of world maps maintained by users across the globe. It includes all the freeways, major roads, and many minor streets of every major city. The OSM data can be used to generate the network of roads for the Virtual Reality module in Figure 2. Missing data, such as lane information, traffic control, and signal timings, needs to be obtained from local or state agencies or any existing model.

The proposed architecture can be used for any network with the required information. In this study and for demonstration purposes, the Las Vegas road network was created using OSM data. Lane data, traffic control, and signal settings were obtained from an existing traffic simulation model. To obtain the correct mapping, the coordinates from OSM were matched with those in the existing model. A portion of the roadway network created using this approach is shown in Figure 3. This approach reduces the time required to generate a roadway network for the proposed architecture. Details about this approach are discussed below in Section 2.2.

2.2. Hybrid Simulation Model. Most driving simulators provide background traffic around the virtual driver using survey data and hourly volumes/distributions [13] or the desired traffic density [25, 26]. This approach has limitations to capture congestion related phenomena such as spillback and spillover. Microscopic simulation can be used to capture congestion related phenomena. However, the computational burden and the simulation time can increase significantly with network size. In addition, data needs and modeling time are prohibitively expensive for large-scale micro simulation models.

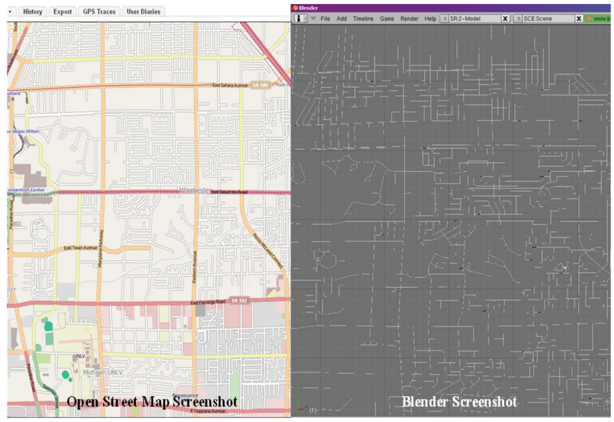

Figure 3: Generated network on Blender using Open Street Map.

In order to adequately represent both the microlevel vehicle dynamics around the virtual driver and the traffic dynamics in the rest of the network, a hybrid simulation model that integrates a microscopic and a mesoscopic traffic flow simulation model is proposed. Félez et al. [27] have envisaged the required environment by integrating a driving simulation engine, SCANeR II, and a microscopic traffic-flow simulation model, AIMSUN. The authors have discussed and proposed solutions for various integration issues such as the matching of roadway geometry, computing speed for data exchange, simulation step size, and autonomous vehicle visualization. The paper also discusses some limitations of the integration including issues with control of the autonomous vehicles, vehicle kinematics in curve sections, and lane changing behavior. The proposed architecture in this study envisions higher consistency at a lower computation cost by integrating various simulators as interdependent components in a single framework. To the best of our knowledge, only Olstam et al. [28] have used a hybrid simulation model to provide background traffic to a driving simulator. The area surrounding the virtual driver was divided into one inner region and two outer regions. Vehicles in the inner region were simulated according to a microscopic model, while vehicles in the outer regions were updated according to a mesoscopic model. The authors mentioned that further research is required to address the following issues: (i) arterials and freeways with three or more lanes; (ii) ramps on freeways and intersections on rural roads; (iii) simulation of urban traffic conditions; and (iv) simulation on roadway networks.

Critical aspects in the development of hybrid simulation models are the compatibility of two different traffic flow streams and the propagation of traffic conditions at the interfaces [29]. Traffic propagation at interfaces should be analyzed both at free-flow conditions and at congested conditions. In mesoscopic models, vehicles move in an aggregate fashion while, in microscopic models, vehicles move according to individual vehicle dynamics. Hence, at the interfaces of meso to micro and micro to meso, traffic propagation both upstream and downstream has to be considered. It is necessary to define the time when both the models will transfer data based on the updating time intervals for the two models [30].

The proposed hybrid simulation model integrates the DynusT© [21], a mesoscopic simulation-based dynamic traffic assignment model, with a microscopic simulation model. The microscopic model includes a car-following model, a lane changing model, and a gap-acceptance model. Background traffic around the virtual driver is provided by the micro simulation model. Hence, the region covered by the micro simulation, called the μSim zone, is defined by the position of the virtual driver. The following methods can be used to define this region:

(1) *Method 1 (Moving μSimlink).* Use the microscopic simulation model only on the roadway link where the virtual driver is present. Show the Virtual Reality Environment to the extent of the driver's visibility limit. Use mesoscopic simulation on all the other links. Thus, the μSim zone is the link where the virtual driver is located and it changes according to the position of the virtual driver.

(2) *Method 2 (Moving μSimzone).* Use the microscopic simulation model in a zone around the position of the virtual driver. Show the Virtual Reality Environment to the extent of the driver's visibility limit. Use mesoscopic simulation on links other than those modeled using micro simulation. Thus, the μSim zone is the fixed zone with respect to position of the virtual driver.

In both methods, the problem of conserving vehicles should be solved at the boundary of mesoscopic and microscopic integration. In each simulation interval of the mesoscopic model, the entire network is updated based on the mesoscopic logic and the states at the boundary between the meso and micro models. However, the network states covered by the micro simulation model govern that zone.

2.3. User-Driven Vehicle Dynamics Model. The objective here is to generate actual vehicle motion dynamics so as to enhance modeling realism. This motion produces physiological and psychological reactions similar to those present in a real-world driving experience. Motion-axis simulators can be used to generate vehicular motion dynamics using DOFs ranging from two to fourteen [8–14, 25]. Implementation should be based on the required aspects for the particular problem context in order to avoid unnecessary computations.

Vehicle motion dynamics are generated using SimCraft 3DOFs motion-based simulator. Although 6DOFs are desired to reproduce most vehicle dynamics, the 3DOFs can realistically reproduce the most important motions such as the effects of acceleration/deceleration as well as changes on roadway geometry. The motion dynamics are generated based on the actions of the virtual driver, the geometric characteristics of the roadway, and the interactions with other vehicles. Hence, motion dynamics must be seamlessly synchronized with the Virtual Reality module.

2.4. Pedestrian, Bicycle, and Motorcycle Simulator. Existing pedestrian models [31, 32] require detailed data to capture the interactions between pedestrians and vehicles. Some studies [33] have focused on the study of pedestrian and driver behavior at crosswalk locations, where pedestrians and vehicles often interact. Numerous data has been collected about both pedestrians and drivers. However, the data collection process can be expensive and limited by the physical and operational characteristics of the location where the data is being collected. Hence, it is difficult to analyze multiple alternatives and the effects of critical factors. Pedestrian simulators enable circumventing some of these issues. The University College London has a Pedestrian Accessibility and Movement Environment Laboratory (PAMELA) [34] to study pedestrian movements under various environmental conditions. PAMELA has been used to better understand roadway aspects that affect pedestrian's ability to navigate the traffic system. The proposed pedestrian, bicycle, and motorcycle simulators have the unique capability of interacting together with a car or driving simulator. This capability enables studying a broad range of transportation phenomena using actual human beings in a safe and controlled environment.

Sensors can be used to capture the movements of various entities as well as human behavior including, for example, a pedestrian observing traffic while crossing a street and the walking speed relative to the traffic conditions. Traffic safety is highly influenced by users' behavior and their interactions. According to a report by the National Highway Traffic Safety Administration (NHTSA) [35], every year at least 50% of the motorcycle fatal crashes involve multiple vehicles; of that percentage, 41% had a blood alcohol concentration of 0.08 g/dL or higher. Safety is a primary concern not only for cars, but also for motorcycles and pedestrians. The proposed simulation framework enables the study of traffic safety for all these users.

The pedestrian simulator consists of a state-of-the-art Natural Interaction Sensor (Microsoft Kinect) and a head-mounted display. The movements of human walking are captured using the Microsoft Kinect. The Kinect consists of sensors that identify joints, body structure, facial features, and voice. The head-mounted display is to project the traffic conditions for the pedestrian. These traffic conditions are obtained using the communication module in the pedestrian simulation client.

2.5. Virtual Reality Environment. The Virtual Reality Environment is used to provide all the background as well as the traffic conditions representing the real-world to the various human beings navigating the system using the proposed simulators. The Virtual Reality Environment includes seven different components: simulation, interaction, artificiality, immersion, telepresence, full-body immersion, and network communication [36]. These components are used to provide an immersive traffic experience subject to hardware and software limitations.

In this study, the Virtual Reality Environment is created using 3D models [14]. To accelerate the modeling process and to achieve cost-effective development, an automated modeling process is required. A challenging problem for automation is creating and deploying 3D models at the required exact locations without deforming their sizes and shapes. Here, a hierarchical multilayer and data-driven approach is

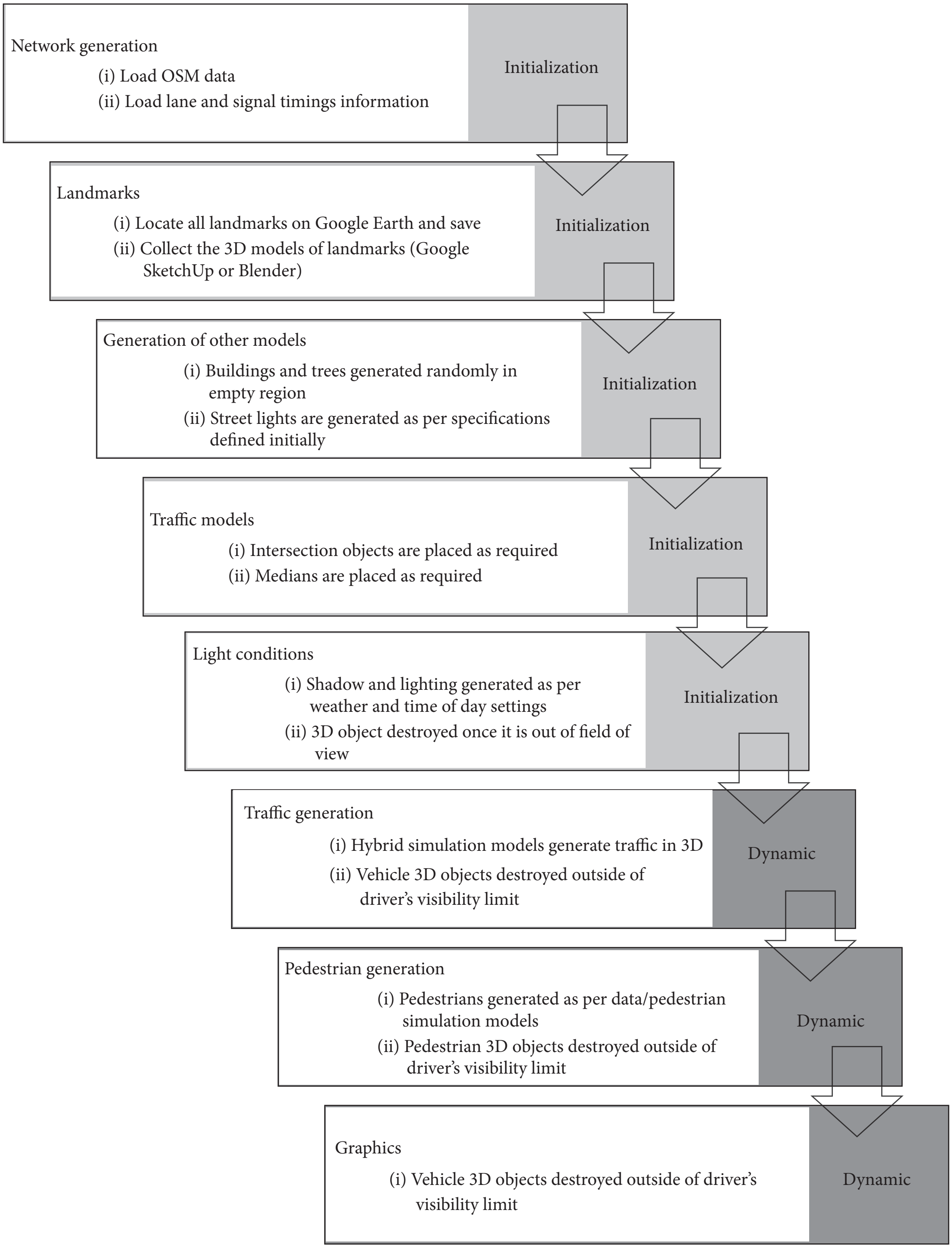

Figure 4: Layer-architecture for Virtual Reality generation.

proposed. Each layer includes different types of objects which are recreated using data obtained from various sources.

Figure 4 illustrates the proposed multilayer approach for the generation of the Virtual Reality Environment. A list of landmarks is created and imported from Google Earth. Similarly, 3D images for the imported list are obtained from Google SketchUp [37] or created in Blender [20]. Landmarks are used to provide a perception of familiarity in the Virtual Reality Environment. The location of these models is automated using their latitudes and longitudes. The locations of other objects including trees and buildings and such roadside components as mailboxes, water pumps, fire hydrants, bus stop shelters, and street lights are defined as realistic as possible.

The Virtual Reality Environment is generated only to include the visibility limits for the virtual driver(s) and virtual pedestrian(s). The generated Virtual Reality Environment includes pedestrians as well as different classes of vehicles, such as cars and trucks. Different levels of visibility are available according to weather and time of day conditions. These conditions are recreated using various rendering techniques such as shading and reflecting.

2.6. Results and Discussion. One of the primary objectives of the proposed architecture is the collection of data about the vehicles, the users, and the system performance. Vehicle data includes variables such as lateral position, vehicle trajectories, vehicle heading angle, acceleration/deceleration, and braking times. Users' data includes variables such as perception-reaction times, physiological data obtained from electrocardiograms, galvanic skin response, and body temperature. The hybrid simulation model will collect system performance data. The data collection module is included in every single client so as to collect the corresponding information.

The initial implementation of the proposed architecture began with control of the driving simulator using the Software Development Kit (SDK) provided by the manufacturer, SimCraft. A control module was created using a Dynamic Link Library (.dll) file provided in SDK. Blender [20] was chosen for the development of graphics because it provides the required minimum capabilities. Blender is open source and has a big user base and a support community. In addition, Blender [20] is supported in both Linux and Windows. Once the graphics of roadway network were developed, a vehicle model was created to drive in the network. The scripts developed in this study can be used to generate models of the transportation network of any city. This requires using Open Street Maps.

Microsoft Kinect is currently being used for the development of the pedestrian simulator. A walk identification module has been created with a text output. This will later be developed and integrated into the pedestrian simulator. Blender [20] is used for creating 3D models for various transportation components, such as different roadways, traffic signal displays, buildings, and trees. The proposed architecture requires views inside the Virtual Reality Environment for cars, motorcycles, bicycles, and pedestrians. Multiple CPUs are used to generate these views. A networking module was developed to enable data transfer across the multiple CPUs. CORBA is used for this purpose along with omniORB C++ and Python.

Future work includes (i) the implementation of hybrid simulation model for the driving and pedestrian simulators; (ii) the graphics module for Virtual Reality Environment; (iii) the development of hardware for bicycle and motorcycle simulator; and (iv) the integration, coordination, and synchronization of all the components of the proposed architecture.

3. Conclusions

This study has proposed an architecture for an interactive and motion-based simulation of a vehicular and pedestrian traffic system. The proposed architecture increases the realism of existing alternative modeling approaches by explicitly and simultaneously including actual drivers, pedestrians, and bikers. In addition, the architecture enables the modeling of the entire network with reasonable investment of resources. To the best of our knowledge, there is no alternative architecture that simultaneously considers all the elements of reality considered here. Existing modeling frameworks focus on a particular component of the real-world system; the reaming components are ignored or modeled using artificial entities. State-of-the-art modeling and analysis tools such as simulation-based Dynamic Traffic Assignment, CORBA, and Open Street Maps enable the implementation of the proposed architecture. Implementation of the architecture will provide the unique capability to study countless traffic problems using actual human beings.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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