Hindawi
Wireless Communications and Mobile Computing
Volume 2017, Article ID 6457942, 14 pages
https://doi.org/10.1155/2017/6457942

Review Article

Energy Efficient Hierarchical Clustering Approaches in Wireless Sensor Networks: A Survey

Bilal Jan,[1] Haleem Farman,[2] Huma Javed,[2] Bartolomeo Montrucchio,[3] Murad Khan,[1] and Shaukat Ali[2]

[1]*Department of Computer Science & IT, Sarhad University of Science and IT, Peshawar, Pakistan*
[2]*Department of Computer Science, University of Peshawar, Peshawar, Pakistan*
[3]*Department of Control and Computer Engineering (DAUIN), Politecnico di Torino, Torino, Italy*

Correspondence should be addressed to Bilal Jan; bilal.csit@suit.edu.pk

Received 24 May 2017; Revised 2 September 2017; Accepted 11 September 2017; Published 29 October 2017

Academic Editor: Pierre-Martin Tardif

Wireless sensor networks (WSN) are one of the significant technologies due to their diverse applications such as health care monitoring, smart phones, military, disaster management, and other surveillance systems. Sensor nodes are usually deployed in large number that work independently in unattended harsh environments. Due to constraint resources, typically the scarce battery power, these wireless nodes are grouped into clusters for energy efficient communication. In clustering hierarchical schemes have achieved great interest for minimizing energy consumption. Hierarchical schemes are generally categorized as cluster-based and grid-based approaches. In cluster-based approaches, nodes are grouped into clusters, where a resourceful sensor node is nominated as a cluster head (CH) while in grid-based approach the network is divided into confined virtual grids usually performed by the base station. This paper highlights and discusses the design challenges for cluster-based schemes, the important cluster formation parameters, and classification of hierarchical clustering protocols. Moreover, existing cluster-based and grid-based techniques are evaluated by considering certain parameters to help users in selecting appropriate technique. Furthermore, a detailed summary of these protocols is presented with their advantages, disadvantages, and applicability in particular cases.

1. Introduction

Wireless sensor network is the collection of wireless nodes that are often randomly deployed in a targeted area over vigorously changing environments. These nodes can sense, process, and forward data to neighbouring nodes and base station (BS). Moreover, these small devices have limited capabilities such as small memory, low computation, low processing, and most importantly small power unit (usually equipped with batteries). The sensor nodes are scattered over a large geographic area containing hundreds of nodes to monitor a target region. As the sensed data has to be forwarded to BS for further necessary action, therefore routing becomes important for transferring of data from node to node or BS efficiently [1–4]. The WSN has been acknowledged as one of the significant technologies of the 21st century. A tiny, low cost device having sensors on board, connected wirelessly with self-organizing capability, can be connected to the Internet for controlling and monitoring environments, homes, offices, cities, and much more [5]. These sensor nodes can be deployed anywhere on the ground, underwater, on bodies (WBAN—Wireless Body Area Network), in the air, inside buildings, and even in vehicles (VANETs—Vehicular Ad Hoc Networks). Since 2001, researchers and industrialists have shown great interest in developing WSN communication capabilities and have used sensors in a variety of other technologies such as IEEE 802.11, personal digital assistants (PDA), VANETs, mobile phones, and Internet of Things (IoT) [6–10].

In WSN, to efficiently utilise the available resources especially battery, different hierarchical techniques have been proposed. The goal is to obtain energy efficiency and maximize network lifetime. In hierarchical routing, clustering is the most widely used technique to achieve these goals. Clustering schemes by design eliminate the redundant

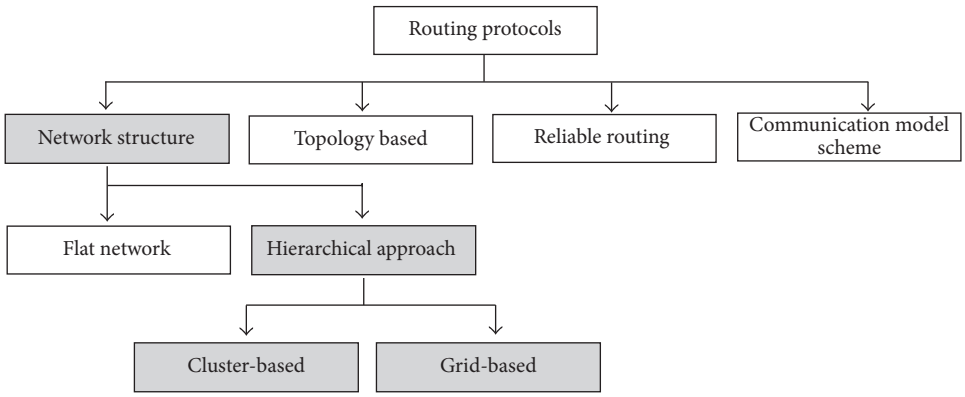

Figure 1: Classification of routing protocols in WSN.

messages in formation of efficient clusters and intelligent selection/reselection of the CH. In literature, researchers have proposed various clustering protocols, but issues such as optimizing energy efficiency and load balancing require further research. Moreover, topology construction is also vital to distributing nodes uniformly in the clusters or grids in case of grid-based approaches to make the network efficient. The periodic reformation of clusters and reselection of CH results in excessive energy consumption that could lead to poor network performance [2, 11, 12].

Routing in wireless sensor networks is more challenging than other wireless networks such as mobile ad hoc network or vehicular ad hoc networks, as WSN has resource constraints [13]. Therefore, to meet the challenges in WSN, new routing mechanisms are being developed keeping in view the application requirements and the underlying network architecture. Due to frequent topological changes in the network, maintaining routes is a major issue and if not carefully handled may result in high energy consumption. To minimize energy consumption and to prolong overall network lifetime, various routing techniques have been introduced in the literature. Furthermore, they can be broadly categorized into four classes: network structure, topology based, reliable routing scheme, and communication model scheme [1]. Each class is further divided into subcategories as shown in Figure 1. The focus of this work is on the highlighted subcategories as shown Figure 1. The network structure is further categorized into flat and hierarchical protocols. In flat networks, all sensor nodes cooperate with each other through multihop routing in which each node has the same role. It is not feasible to have an identifier (ID) for each node, due to which data-centric routing is considered for flat routing in which BS requests from sensors in a specific region. The flat based approach has some advantages such as no need to maintain topology and provides quality links from source to destination. However, flat networks use flooding which is an expensive operation in terms of energy consumption. Moreover, flat network causes high bandwidth consumption due to redundant messages and has nonuniform energy consumption with high delay [14].

In hierarchical approaches, nodes are clustered into groups, and, by some criteria, a cluster head is selected that is responsible for routing. In hierarchical routing, usually two-layer approach is used, where one layer is used for sensing the physical environment and the other is used for routing. The low energy nodes are used for sensing while high energy nodes are often used for collecting, aggregating, and forwarding data [33]. Clustering approach is the most widely used technique for energy efficiency to achieve scalability and effective communication. Cluster-based hierarchical approaches have some advantages such as increasing scalability; efficient data aggregation and channel bandwidth are efficiently utilised. The main problem of clustering is nonuniform clustering which leads to high energy dissipation of sensor node, total energy consumption increases, and network connectivity not being guaranteed [14, 34]. The focus of this work is on hierarchical clustering schemes.

The main contribution of this work is to provide a survey of existing energy efficient hierarchical clustering approaches, and, by network structure, they are classified into cluster-based and grid-based techniques. The main focus is on cluster formation, cluster head selection, cluster reformation, and cluster head reselection taking in to account the energy consumption and their effect on overall network lifetime. Furthermore, the advantages and disadvantages are discussed, and a detailed summary is drawn on behalf of both hierarchical approaches to help researchers and experts to select the most appropriate technique based on application requirement. It is worth mentioning here that this work is focused only on hierarchical energy efficient clustering protocols.

The rest of the paper is organized as follows. In Section 2, clustering in WSN is explained along with the design challenges, clustering parameters, and taxonomy of hierarchical clustering. Section 3 is about hierarchical clustering approaches, and various cluster-based and grid-based techniques are explained in detail. The cluster and grid-based techniques are summarized along with strengths and weaknesses in Section 4. The open issues in a wireless sensor network are discussed in Section 5. In the end, the paper is concluded in Section 6.

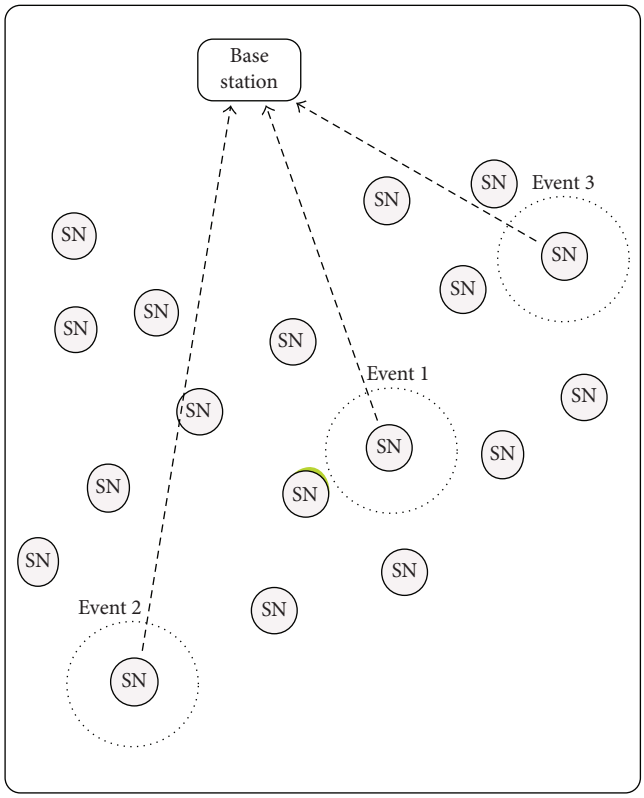

Figure 2: Direct communication.

2. Clustering in WSN

Due to scarce resources in WSN, direct communication of sensor node with BS or multihop communication of sensor nodes towards BS is not practical as energy consumption is high which results in early expiry of sensor nodes as shown in Figure 2. Direct communication or single-tier communication is not feasible for large scale network as WSN cannot support long-haul communication. Direct communication has its disadvantages such as high energy consumption, duplication of data (sensor nodes that were close to each other, sending data with very small variation), and farthest nodes dying quickly. To overcome these problems, two-tier communication through hierarchical approach is used where nodes are grouped into clusters. Leader node also called cluster head (CH) is responsible for aggregating the data and then forwarding it to the BS.

Hierarchical network structure often makes a two-level hierarchy, in which the cluster heads are placed at the upper level, and the lower level is for member nodes. The lower level nodes periodically send data to their respective CH. The cluster head then aggregates that data and forwards it to BS. The CH node spends more energy than member nodes, like all the time CH node is sending data over long distances [1, 35]. Moreover, after certain rounds, the selected CH may be unable to perform or perish due to high energy consumption. In order to ensure load balancing among sensor nodes, the role of CH is changed periodically to balance the energy consumption [3, 36]. Communication within a cluster is single-hop (intracluster) and between clusters is multihop (intercluster) as shown in Figure 3. Cluster-based and grid-based techniques are the most commonly used hierarchical techniques [11].

2.1. Design Challenges in Clustering. Wireless sensor network presents some challenges regarding design and implementation of clustering algorithms [37]. In most of the WSN outdoor applications in unattended environments, it is not easy to recharge the battery or replace the entire sensor. Due to limited hardware, the processing capabilities also need to be considered. A lightweight clustering algorithm is required because of the limited memory. Moreover, with these restrictions, it is very difficult to manage scalability and prolong network lifetime. Along with the above-mentioned limitations, following are some other challenges which need to be addressed properly while designing clustering algorithms.

The cluster formation process and the number of clusters are very important factors in clustering protocols. The clusters should be well balanced, and the number of messages exchanged during cluster formation should be minimized. The complexity of the algorithm should increase linearly as the network grows. Cluster head selection is another important challenge that directly affects the network performance. The best possible node should be selected so that the network stability period and overall network lifetime should be maximized [38]. In most of the techniques, CH selection is based on several parameters such as energy level and the location of the node. Data aggregation is performed on the sensed data received by CH from member nodes; that is why it is still considered as the fundamental design challenge [39, 40]. It should also be considered that the designed clustering algorithm should be able to handle different application requirements, as WSN is application dependent. Another very important factor is to make sure that the designed algorithm is *secure* enough and can be used in applications where data is very much sensitive such as a military application or health monitoring.

2.2. Clustering Parameters. Clustering parameters that can directly or indirectly affect the cluster formation process [41] are discussed below.

(i) Cluster Count. In most of the existing approaches, cluster head selection and cluster formation lead to different cluster count, where the number of clusters is predefined. It is a key parameter concerning clustering algorithm efficiency, which varies depending on network size.

(ii) Cluster Formation. The approach of cluster formation can be centralized where the decision of cluster formation is handled by BS, while in distributed approach clusters are formed without any coordination. In literature, hybrid

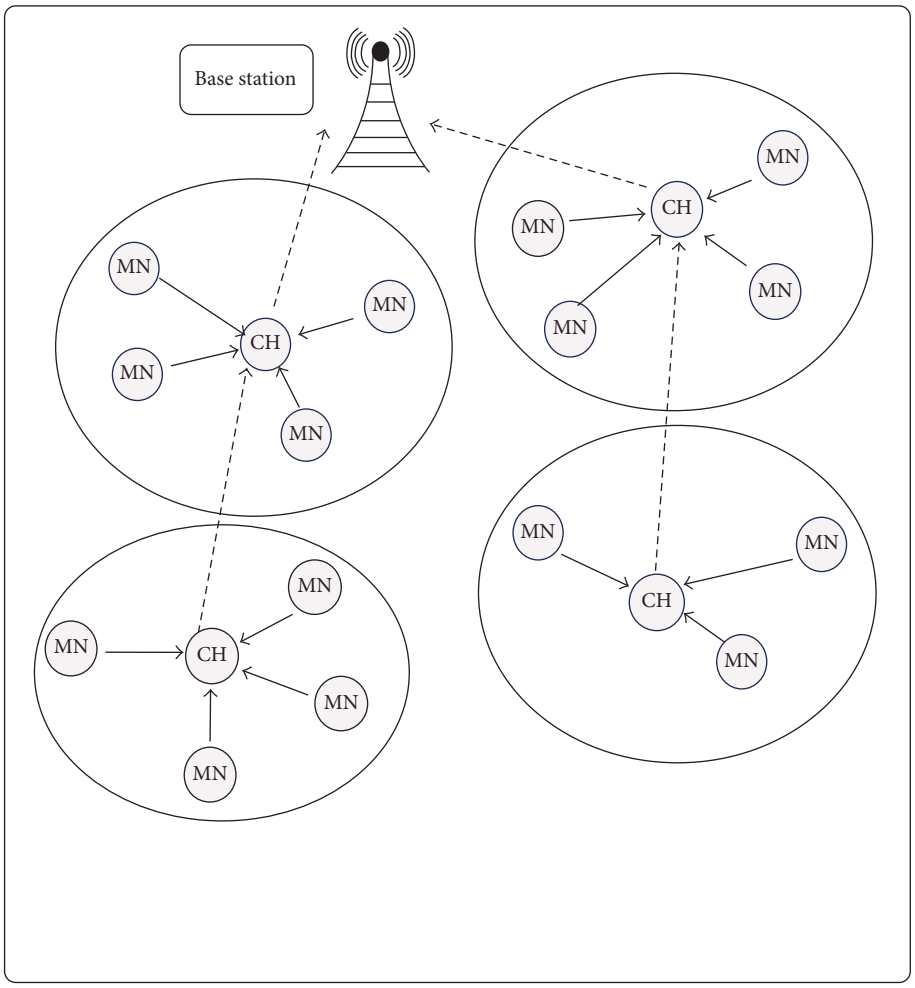

Figure 3: Cluster-based communication.

approaches are also being used where the advantages of both approaches are used.

(iii) Intracluster Communication. It means the communication of sensor nodes with its elected CH within a cluster. In most of the approaches sensor nodes directly (one-hop) communicate with CH as it depends on the distance between node and CH. In large scale network, multihop communication may also be adopted for intracluster communication.

(iv) Mobility. In static network, the sensor nodes and cluster heads are static results in stable clusters. Moreover, static position of nodes results in facilitated network (intracluster and intercluster) management. The cluster and CH evolve concerning time if the nodes change their position, thus requiring continuous maintenance [42].

(v) Node Types. In the existing proposed approaches, some of them have used heterogeneous nodes, and some have used homogeneous nodes in a network. In a heterogeneous environment, usually, CHs are equipped with high communication and computation resources than normal nodes. While in the homogenous network, all nodes have same capabilities and few of them are nominated as CH through efficient techniques [42].

(vi) Cluster Head Selection. The overall network performance also depends on cluster head selection. In some proposed techniques, the cluster head is predefined (usually in heterogeneous environments). In most cases, the CH selection is based on various parameters (distance from nodes and center, energy level, etc.) or probabilistic approach is used or it is done through any random technique.

(vii) Multilevel Cluster Hierarchy. In literature, several techniques used the concept of the multilevel cluster to attain even improved energy consumption and distribution. Sensor node communicates with CH in their respective level 1 clusters

which further communicates with level 2 clusters. In this approach, intercluster communication is of high significance, especially for large scale networks.

(viii) Algorithm Complexity. Another important parameter in clustering is the algorithm complexity; aim of recent algorithms is the quick formation of clusters and selection of CH. In most techniques, the time complexity or convergence is kept constant while in some it depends on a number of sensor nodes in a network.

2.3. Taxonomy of Hierarchical Clustering Approaches. In WSN, the existing clustering protocols fall into different groups, that is, (i) homogeneous and heterogeneous networks, (ii) centralized or distributed algorithms, (iii) static and dynamic clustering, (iv) probabilistic and nonprobabilistic algorithms, and (v) uniform and nonuniform clustering approach.

(i) Homogeneous and Heterogeneous Networks. The clustering techniques for homogeneous and heterogeneous networks are built on the characteristics and capability of sensor nodes in a cluster. In *homogenous* networks, all of the sensor nodes have similar processing and hardware capabilities [43]. Moreover, based on various parameters such as residual energy level and distance from the center of a cluster, every node can be a CH. To achieve energy efficiency and load balancing, the role of CH is rotated periodically, while in *heterogeneous* networks, where there are usually two types of sensor nodes, nodes with higher hardware and processing capabilities are usually used as CH within a cluster, function as data collectors, or even can be used as a backbone within the network. Nodes having lower capabilities are common sensor nodes that sense the desired field attributes [44, 45].

(ii) Centralized or Distributed Algorithms. In *centralized* algorithms, usually, CH or BS is responsible for network partitioning and cluster formation. These types of algorithms are usually not suitable for large scale networks and more suitable for limited-scale applications. Whereas, in the *distributed* techniques CH election, selection and cluster formation are done by the sensor nodes themselves to gain flexibility and quick execution and convergence time. Usually distributed algorithms are more commonly used in the homogeneous environment. Hybrid techniques are also used where advantages of centralized and distributed algorithms are utilised [46].

(iii) Static and Dynamic Clustering. Clustering in WSN can be static or dynamic depending on the application requirements. In *static* clustering, the cluster formation and CH election are fixed. Once clusters are formed, and CH are elected, then it will remain for a long time. In most of the techniques, clusters are formed once, but CHs are periodically changed to gain energy efficiency. *Dynamic* clustering offers high energy efficiency by the periodic reelection of CH and reformation of clusters. It is used, where topology frequently changes and clusters needs to reorganize to effectively react to topological changes and leads to improved energy efficiency [47].

(iv) Probabilistic and Nonprobabilistic Approaches. In *probabilistic* clustering approaches, each sensor node is assigned a prior probability to decide whether the CHs or any random selection technique is used [48, 49]. Moreover, the probabilities assigned to nodes act as primary criteria, but some other secondary criteria can also be used during the process of CH reselection or cluster reformation for improved energy consumption and maximizing network lifetime. Also, these techniques have fast execution and convergence time and minimize the number of exchange messages. In *nonprobabilistic* clustering techniques, deterministic criteria are considered for CH election and cluster formation/reformation. In addition, it mainly depends on the information received from one-hop or multihop neighbours and requires excessive messages to be exchanged resulting in worse time complexity than the probabilistic approaches. Moreover, nondeterministic approaches give more reliable, robust, and balanced clusters, as the selection is based on multiple criteria such as residual energy, node proximity, mobility, and transmission power [50].

(v) Uniform and Nonuniform Clustering Approach. In *uniform clustering approach*, the number of nodes is evenly distributed among clusters to achieve energy efficiency. However, it is often applicable in environments where nodes are static, and their location is predefined [51]. In literature, several efforts are made to achieve an even distribution of nodes through uniform clustering approaches. Moreover, in *nonuniform clustering,* the number of nodes is not uniform per cluster. In clustering, many to one pattern is used for data forwarding; nodes nearer to BS are used frequently which leads to high energy consumption. Most of the deployment in WSN is random, where sensor nodes are distributed unevenly. Some efforts are made to come up with some solutions regarding the uniform distribution of load and to achieve energy efficiency through nonuniform deployment of nodes.

On the basis of the above classifications, clustering has been widely used for various applications in different environments to attain energy efficiency and network scalability in WSN. Instead of sending messages to all nodes, a head node is responsible for forwarding data to the BS to preserve energy. In addition, clustering technique can simplify management of the nodes, reduce energy consumption, improve load balancing, increase scalability and robustness, and improve data aggregation. In literature, different hierarchical clustering schemes are proposed for energy efficiency and maximizing network lifetime. Few of them are discussed in the forthcoming section.

3. Hierarchical Clustering Approaches

In literature number of different techniques are proposed for the development of hierarchical clustering protocols based on application requirements. The protocols are designed keeping in view some important factors such as energy efficiency and overall network lifetime. In literature, there are various surveys on different routing protocols in WSN, but, in this paper, the focus is on different hierarchical clustering approaches. Moreover, parameters such as the formation of clusters and CH selection are considered. Furthermore, the differences are highlighted along with advantages and

disadvantages. The hierarchical clustering is further divided into cluster-based and grid-based approaches which may fall in to one or more of the above-discussed classification and these techniques are further explained below.

3.1. Cluster-Based Hierarchical Approaches. Clustering approaches are used to simplify the node management, to reduce energy consumption, to achieve scalability, and to improve load balancing and robustness and data aggregation. Nodes are grouped to form clusters. A node that is known as a cluster head (CH) is made responsible for gathering data from member nodes (MN), aggregates it, and then forwards to the BS directly or through some intermediate CH as shown in Figure 3. Instead of sending data of all sensor nodes in a cluster, CH only sends the aggregated data, which in turn minimize the number of packets transmitted in a network and minimize energy consumption. The data received from a CH node is further processed at the base station, where end users access it. The position of BS can be within a field or can be placed outside the network area. Usually, BS is placed outside and at a distance from the sensor nodes. The data sensed by sensor node is forwarded through a gateway (CH) to the BS. The multilevel clustering hierarchy can have more than one BS in the network (if needed). In literature, various attempts have been made to improve the energy efficiency through different clustering techniques by addressing the problems of efficient cluster formation, even distribution of load, CH selection and reselection, and cluster reformation [2, 15–20, 36]; few of them are discussed here.

(i) Low Energy Adaptive Clustering Hierarchy. Low energy adaptive clustering hierarchy (LEACH) was proposed by Heinzelman et al. [15], which was one of the first energy efficient routing protocols and is still used as a state-of-the-art protocol in WSN. The basic idea of LEACH was to select CH among a number of nodes by rotation so that energy dissipation from communication can be spread to all nodes in a network. The operation is divided into two phases, the setup phase and steady-state phase. In the setup phase, each node decides whether to become a CH or not for the current round which depends on the CHs percentage suggested and a number of times a node has been CH. A random number is chosen from 0 to 1; if the number is less than threshold, the node becomes a cluster head as shown in

$$T(n) = \begin{cases} \dfrac{P}{1 - P(r \bmod (1/P))}, & \text{if } n \in G, \\ 0, & \text{otherwise}, \end{cases} \quad (1)$$

where P is the percentage of CHs, r represents current round, and G shows member nodes that have not been selected as CHs in the last $1/P$ rounds. The elected CH will advertise a message to other nodes and, on the basis of received signal strength, nodes decide which cluster to join and will send a membership message. To efficiently utilise the energy, the role of CH is rotated. The second phase is the steady-state phase, in which nodes sense and transmit data to its CH which is then aggregated and sends to BS directly. In order to avoid collisions, TDMA/CDMA MAC is used. Due to distributed approach LEACH does not require any global information. Various modifications have been made to LEACH in literature such as MR-LEACH [52], LEACH-B [53], ER-LEACH [54], and ID-LEACH [55]. LEACH has some disadvantages such as probabilistic approach using random number for cluster head selection, which might result in suboptimal CH node thus resulting in high energy consumption. Furthermore, the dynamic clustering overhead and nonuniform distribution of CH will consume more energy and lead to poor network performance.

(ii) Low Energy Adaptive Clustering Hierarchy Centralized. Low energy adaptive clustering hierarchy centralized (LEACH-C) [16] is the modified version of LEACH. In LEACH-C the clusters are formed by base station whereas in LEACH each node self-configures them into cluster. The BS receives all the information regarding the energy and location of all the nodes deployed in the network. By doing so, BS determines the number of cluster head (CH) and arranges network into various clusters. However, due to lack of coordination among nodes, the number of CHs varies from round to round. In LEACH-C the number of CHs in each round equals an optimum determined value. A centralized routing approach is one in which BS computes the average energy of a network for a set of sensor nodes having energy level above average. A CH will be selected from the set of nodes to ensure that nodes selected should have sufficient energy to be a cluster head. The network is split into two subclusters and then they are further divided into the desired number of CHs. By this way, the nodes are evenly distributed to ensure that load is eventually distributed. The BS selects lowest energy routing paths and forwards the information of clustering and CH to all nodes in the network using a minimum spanning tree approach. However, due to centralized approach communication overhead will increase in the reselection of CH, because reselection decision has to be made by BS. In addition, every cluster will send request; thus energy consumption will be high.

(iii) Cluster Chain Weighted Metrics. Cluster chain weighted metrics (CCWM) [17] achieve energy efficiency and increase network performance based on weighted metrics. A set of CHs is selected depending on these metrics. Member nodes use direct communication for transferring data towards their respective CHs. A routing chain of elected CHs is constructed for interclusters communication and each CH forwards data to its neighbouring CH until it reaches BS. The authors claim that CCWM improves overall network lifespan. However, due to nonoptimized CH election, the reelection of CH results in network overheads. Moreover, intracluster communication is direct which leads to uneven energy consumption.

(iv) K-Means Algorithm. The cluster head is selected using K-means algorithm to prolong overall network lifespan [18]. Authors divided the whole process into three phases. LEACH protocol is used to determine initial CH selection. Further, the network is partitioned into k clusters, based on the Euclidean distance nodes join their nearest CH. Once the nodes join the CH, center of each cluster is determined and

each node is assigned an ID based on the distance from centroid. Node closer to the center will have smaller number. CH is rotated and the next comparative nearer node to the center is selected as new CH. As compared to other schemes, it improves overall network lifetime but periodic reformation of clusters results in additional network overhead and high energy consumption. Moreover, as clusters are formed in random manner initially thus it can result in suboptimal clusters and uneven distribution of load.

(v) Cluster Head Election Using Fuzzy Logic. Authors in [19] proposed cluster head election approach using fuzzy logic (CHEF). Based on random number, tentative CHs are elected in each round. The elected CH then uses two fuzzy parameters which are local distance and energy level. Local distance is basically the sum of all distances from neighbouring nodes. By using fuzzy if-then rules, each CH determines its chance value and then advertises it. CH having greater chance value will be selected as CH and will advertise itself so that member nodes can join it. CHEF improves network lifetime as compared to earlier solutions but due to periodic messages it adds network overhead and unnecessary traffic load. Furthermore, cluster head election process is expensive in terms of energy consumption as it is performed in the entire network that results in high energy consumption.

(vi) Unequal Clustering Size Model (UCS). A variable size clustering scheme called Unequal Clustering Size (UCS) for wireless sensor network is proposed in [20]. It is assumed that sensing field is circular and is divided into two layers. Clusters in layer one have the same shape and size while layer two will have different shape and size. The problem of unbalanced energy consumption is addressed in UCS model. To keep the energy consumption minimum, the CH must be positioned somewhere or near to the center of a cluster. Area covered by the clusters can be altered in each layer by changing radius of a layer near to BS and hence will change density of a particular cluster. The authors claimed that this model works well in homogenous networks and provides balanced energy consumption through unequal clustering approach especially for network that deals with large amount of data. One of the limitations of this approach is the number of nodes per cluster, as in WSN deployment is often random and the number of nodes per cluster may vary to a great extent. Furthermore, the optimal number of CH per layer is another concern as the approach deals with multiple layers.

(vii) Nonuniform Deterministic Node Distribution. The weaknesses of uniform clustering is pointed out in nonuniform deterministic node distribution (NUDND) [21], where it can lead towards energy hole in the network. A new model nonuniform deterministic node distribution is proposed, where node density increases towards sink node. As nodes nearer to BS will be used more than other nodes in the network, a simple distributed algorithm is introduced to load balanced data gathering. The proposed technique might work well in predefined node positions but in random deployment nodes are often scattered which can lead to energy hole problem.

(viii) Energy-Aware Distributed Clustering (EADC). Energy-Aware Distributed Clustering (EADC) [22] is proposed for nonuniform deployment of sensor nodes to balance the load across the entire network. EADC constructs unequal clusters to solve the problem of energy holes. Through routing algorithm, the CHs choose nodes with high energy along with least hop count to member nodes to achieve load balancing in CHs. The cluster head is then selected on the basis of the ratio of average remaining energy of nearby nodes and the energy of node itself. Some of the sensor nodes were redundant, consuming extra energy which was ignored in EADC. This problem was solved in [56]; the redundant nodes were turned OFF based on the schedule. Furthermore, the overall energy consumption was reduced by avoiding unnecessary sensing and transmission.

(ix) LEACH-MAC. In [23], low energy adaptive clustering hierarchy-media access control (LEACH-MAC) is presented to control the randomness of cluster head count in LEACH protocol. The problem of LEACH is that it selects the CH on the basis of random number; nodes that generate the random number less than the threshold will become CH. Authors have addressed the problem of randomness by using media access control layer information. To achieve energy efficiency, LEACH-MAC selects the CH based on uniform random interval to make the CH count stable. Although authors have achieved stability in terms of CH count, the selection of CH is primarily based on threshold value. Therefore, important parameters are still ignored in the selection process.

(x) Energy-Aware Distributed Unequal Clustering. The problem of energy hole was addressed in energy-aware distributed unequal clustering (EADUC) [24] by considering unequal sized clusters. Nodes having different energy resources are considered and clusters with unequal sizes are constructed to solve the energy hole problem. Authors claim that the obtained results were better in comparison with LEACH regarding energy efficiency and maximizing network lifetime. EADUC achieves energy efficiency through unequal cluster formation. However, the redundancy of data in dense area is not considered in EADUC which leads to unnecessary energy consumption affecting network lifetime.

3.2. Grid-Based Approaches. In grid-based clustering techniques, the whole area is partitioned into virtual grids. The grid-based techniques are popular due to their simplified management. The CH selection is usually done by the nodes themselves which makes it suitable for large scale networks. The focus of this work is on grid-based clustering. The main objective of grid-based techniques is to more effectively utilise the limited resources especially battery, which is usually not replaceable nor rechargeable. Gridding significantly contributes to overall network lifespan, energy efficiency, and system scalability. Grid-based techniques are very useful for scalable networks where some nodes in a network are hundreds and even thousands in number. In addition to the objectives mentioned above, grid-based clustering offers some other secondary advantages which add up to the overall network performance. Through gridding, the routing table of

a single node can be reduced by localizing the route setup. Due to grids, the network topology maintenance overhead can be cut down at the sensor node level thus resulting in the more stable network. CH can switch the member nodes to low power or sleep mode to reduce the energy consumption. Due to all of the above-discussed objectives, grid-based clustering techniques are widely used by researchers to achieve energy efficiency and prolong network lifetime [11, 25–29, 57]. Some of the existing grid-based approaches proposed in the literature are discussed with advantages and disadvantages, which are below.

(i) Grid-Based Data Dissemination. In grid-based data dissemination (GBDD) [25], BS divided the network into equal sized square grid cells. The node that first shows interest in sending data is set as a crossing point (CP) of the grid, and its coordinates become the starting point for the grid cells creation. The cell size depends on the twofold range of sensor nodes. Every node works in two modes, high power radio (high range transmission) and low power radio (low range transmission). In intelligent grid-based data dissemination (IGBDD) [57] network is partitioned into virtual grids. It is the enhanced version of GBDD in which CH selection is based on the location of the virtual cross point (CP) and there is no need to send any data to the neighbouring nodes for CP selection. In IGBDD linear programming is used to select CP to increase overall network lifespan. GBDD guarantees continuous data transfer from source to destination but consumes extra energy when the speed is high.

(ii) Grid-Based Hybrid Network Deployment Scheme. The authors have used a grid-based hybrid network deployment approach (GHND) [11], in which the whole network is divided into virtual squared grids, where each grid represents a zone. Initially, the network topology is constructed using centralized approach, in which BS initiates the grid formation and cluster head selection process. To evenly distribute the nodes, authors have used merge and split technique. Zones with low density and high density are identified and called candidate zones on the basis of lower bound (LB) and upper bound (UB). If a number of nodes is less than LB, then nodes in that particular zone are merged with neighbouring zones depending on weighted score called weighted merge score (WMS). On the other hand, if the number exceeds UB, the BS will split the zone into subzones using any splitting strategy. Four strategies are introduced, namely, horizontal, vertical, diagonal 45°, and diagonal 135°. In order to achieve energy efficiency, the nonprobabilistic approach is used for cluster head selection based on various parameters. The authors claimed that the proposed method enhances network stability and lifetime and performs better than LEACH, PEGASIS, and CBDAS. However, authors applied this on a limited number of nodes but how will it perform in the large scale network is not addressed. Furthermore, the optimal number of grids is not tackled which limits this approach to specific network topology.

(iii) Cycle Based Data Aggregation Scheme. Cycle based data aggregation scheme (CBDAS) [26] is a grid-based approach where the whole network is divided into 2D square sized grid cells. In CBDAS cyclic chain is constructed where each cell head is linked to another cell head. In each round, one cell head acts as a cyclic head (selected by BS) having high energy level. Each cell head will only transmit data to the cycle head. Through cycle head, the amount of traffic is reduced, and energy consumption is less because only cycle head is responsible for communicating directly with BS. The disadvantage of CBDAS is that cycled head can be far away from BS thus consuming more energy due to long distance and may die early. Furthermore, far away nodes will suffer from such problem and can partition the network by breaking chain.

(iv) Distributed Uniform Clustering Algorithm. A distributed uniform clustering algorithm (DUCA) [27] is introduced to evenly distribute the cluster heads and to decrease the differences in the cluster sizes. Grid approach is used for clustering, but each grid does not represent a cluster. Overlapped regions are identified which helped in reducing the cluster sizes, as it often occurs in random deployment. The cluster head selection is based on LEACH which selects the CH based on random number thus ignoring other important parameters and may lead to the suboptimal selection of CH.

(v) Combination of Grid and Genetic Algorithm for Clustering. A genetic algorithm is combined with grid technique for clustering in wireless sensor network [28]. On the basis of nodes location, the whole grid is partitioned and then using membership degree of the Genetic algorithm the grid midpoints are computed. The dimensionality of high-dimension samples is reduced and then mapped into two-dimensional space. Due to dynamic data of sensors, the clustering midpoints of grids are continuously calculated and dynamically change clustering midpoints. At the end cluster midpoints in grids of different types are transmitted to the sink. Due to periodic calculations and dynamic changes of clustering midpoints increased network overhead and may deplete sensor nodes quickly.

(vi) Path-Based Approach for Data Aggregation. Path-based approach for data aggregation (PBDAS) for wireless sensor networks is a grid based technique that uses single chain [29]. The chain is constructed by connecting the cell heads from farthest row (left to right) and then the subsequent farthest row (right to left). This process is repeated until the nearby row to the BS is reached. The authors claimed that cell head selection based on energy increases network lifetime.

(vii) Grid Sectoring. Grid Sectoring (GS) [30] is aimed at even distribution of load and energy consumption over uniform and random deployment of nodes in the field. In GS the whole network is partitioned into equal sized grids and is further divided into sectors, each representing a cluster. The node which is nearer to the center of a cluster is selected as cluster head. The area of interest is divided into small sectors until an optimum number of clusters are attained. The optimum number of clusters is 5 percent to the number of nodes. In this approach, number of sensor nodes per cluster varies and can

result in isolated nodes thus leading to network partitioning where nodes will be unable to communicate but still have enough energy.

(viii) Grid-Based Reliable Routing. The authors in [12] presented a grid-based reliable routing (GBRR) mechanism, in which virtual clusters are formed on the basis of grids. Features of cluster and grid-based are combined to achieve adaptability for dense and large scale randomly deployed sensors. An active node is selected as head node and to avoid exhaustion of CH, GBRR calculates the effective paths within and between clusters. Moreover, source node does not need to transmit via head node and can bypass it if the route is effective towards the BS. As several grids may represent one cluster, so the area covered by that cluster will be large as compared to other cluster having one grid. Furthermore, the node at the edge of a cluster might lead to suboptimal CH selection where the member nodes may require high energy consumption due to large distance resulting in early depletion of sensor battery.

(ix) Cluster Head Selection Using ANP. In [31], authors used analytical network process for cluster head (used interchangeably with zone's head) selection in WSN. The whole network is divided into grids (zones) for randomly deployed nodes. For topology construction, they followed GHND [11] method to evenly distribute nodes across each zone. Five distinct parameters are considered for zone head (ZH) selection, such as residual energy level, distance from the nearby nodes in that particular zone, distance from the center of the zone, number of times a node has been CH, and whether the node is merged from the neighbouring zone or not. These parameters were assigned weights through pairwise comparison of ANP model. The ANP model was applied to each zone for CH selection to come up with the optimum node based on the above five parameters. A node with maximum weight is selected as CH. Using ANP for CH selection gives optimum node that leads to better utilisation of energy resources and extends network lifetime. Moreover, they used ANP for parameters prioritization to come up with most important ones. However, authors did not consider the computational overhead of using ANP and the mobility of nodes.

(x) Randomized Grid-Based Approach. A randomized grid-based approach for complete area coverage in WSN is presented in [32] to achieve energy efficiency and throughput. The whole area is divided into virtual grids depending on the number of nodes in the deployed area. Instead of selecting a certain percentage of nodes as CH from each grid, a single node is selected for a single grid and is repeated for all grids until it satisfies the whole network area. The 2-Voronoi method is used to deactivate the nodes which are redundant and come up with a minimum number of active nodes that can satisfy the coverage of the whole network. Authors have addressed the problem of an optimum number of grids and percentage of CH in each zone. Energy efficiency is achieved by avoiding redundant nodes. However, if the active nodes do not cover the area, then the step of choosing the percentage of nodes will be repeated resulting in energy overhead.

4. Summary of Hierarchical Clustering Protocols

In this section, the above-discussed cluster-based and grid-based techniques are summarized. The advantages and disadvantages of the existing techniques are highlighted to help researchers to select technique according to their requirement. These techniques were analyzed keeping in view the cluster head selection approach to identify whether the technique is probabilistic or nonprobabilistic. Furthermore, the type of clustering and CH selection is identified to analyze whether to use centralized or distributed or even hybrid. In Table 1, the cluster-based hierarchical protocols are summarized while Table 2 shows the summary of grid-based hierarchical protocols.

5. Open Issues

In this paper, various hierarchical clustering algorithms are discussed based on certain parameters. A detailed comparison of the existing hierarchical clustering algorithms is provided based on these parameters. Though different parameters are selected based on the requirement, but still many issues exist which need further investigation keeping in view its integration with the existing technologies such as Internet of Things (IoT), vehicular ad hoc networks (VANETs), and many more. One of the main issues is its security, as WSN usually operates in open environment which makes security a real challenge. The traditional cryptographic techniques cannot be applied in WSN for secure data transmission due to its limited resources. Therefore, a lightweight mechanism is required that can ensure secure communication with minimum energy consumption. The sensor nodes can be used in VANETs where sensors will be deployed on each vehicle to monitor events. The main objective of VANETs is to provide safety to people when they are on road. Keeping in view the high mobility of vehicles, data aggregation is a real challenge using sensors in VANETs.

In the near future, everything will be connected through Internet, termed as Internet of Things (IoT), where one can connect to anything at home, in the office, and so on. Sensors will be used with IoT to connect these things wirelessly for transferring data. As its name indicates that everything is connected, therefore, a huge amount of data will be generated which will be difficult to manage in terms of its connectivity and retrieval and storage of data and security. This huge amount of data is referred to as big data, and, for retrieving information, we need deep learning techniques that can effectively satisfy the query.

Multimedia sensors are widely used for capturing images in a targeted area or by triggering some event. They are used for surveillance and security purposed to monitor the specific area. Keeping in view the importance of the event, delay and fault tolerance need attention while deploying sensors for such applications.

Table 1: Summary of cluster-based protocols.

Cluster-based hierarchical energy efficient protocols				
Protocol	CH selection approach	Type	Advantages	Disadvantages
LEACH [15]	Probabilistic	Distributed	(i) Nodes equally share load up to some extent (ii) TDMA avoids unnecessary collisions (iii) Allocated time slots avoid excessive energy consumption	(i) Single-hop intercluster communication (ii) Energy holes and coverage problems (iii) CH selection is probabilistic without considering energy (iv) Extra overheads due to dynamic clustering
LEACH-C [16]	Probabilistic	Centralized	(i) Global view of the entire network (ii) Even distribution of load (iii) Energy efficient routes	(i) Network overhead (ii) CH selection is probabilistic (iii) Reselection process is resource expensive
CCWM [17]	Nonprobabilistic	Distributed	(i) Improves routing and network lifetime (ii) Suitable for static and small scale networks	(i) Nonoptimized CH election (ii) Increases network overhead (iii) Not suitable for large scale networks
K-means clustering [18]	Probabilistic/centroid-based	Distributed	(i) Simplified approach (ii) Improved network lifetime	(i) Periodic reformation of clusters (ii) Inefficient distribution of load (iii) Reselection is based on centroid distance
CHEF [19]	Probabilistic/nonprobabilistic	Distributed	(i) Keeping in view the entire network for CH election (ii) Optimal CH selection	(i) Excessive message and communicational overhead (ii) Expensive CH election process in terms of energy consumption
UCS [20]	Nonprobabilistic/probabilistic	Distributed	(i) Balanced energy consumption (ii) Suitable for homogeneous networks	(i) Due to random deployment, the number of nodes may vary a great deal (ii) The optimal number of CH is due to multilayer approach
NUDND [21]	Nonprobabilistic	Distributed	(i) Achieved load balancing (ii) Resolved energy hole problem (iii) Works well in predefined nodes position	(i) Not suitable for random deployment (ii) Not suitable for mobile node and large scale networks
EADC [22]	Nonprobabilistic	Distributed	(i) Achieves load balancing among CHs (ii) Addresses imbalance energy consumption	(i) Redundant messages cause additional energy consumption (ii) Uneven clustering in random deployment
LEACH-MAC [23]	Probabilistic	Distributed	(i) Addresses randomness in CH count (ii) Nodes equally sharing load up to some extent (iii) Achieves energy efficiency	(i) The CH selection being based on random value. (ii) Single-hop intercluster communication (iii) CH selection being probabilistic without considering energy
EADUC [24]	Nonprobabilistic	Distributed	(i) Solves energy hole problem (ii) Maximizes network lifetime (iii) Has unequal clustering strategy	(i) Redundant sensed and transmission messages (ii) Extra energy consumption affecting network performance

Table 2: Summary of grid-based protocols.

Grid-based hierarchical energy efficient protocols				
Protocol	CH selection approach	Type	Advantages	Disadvantages
GBDD [25]	Probabilistic	Distributed	(i) Guarantees continuous data transfer from source to destination	(i) It has communication overhead (ii) Timestamp is used for grid validity and has to reconstruct it, which is an overhead
GHND [11]	Nonprobabilistic	Hybrid	(i) Ensures even distribution of nodes (ii) Is energy efficient (iii) Minimizes network overhead (iv) Improves overall network lifetime	(i) Only suitable for static node (ii) Not suitable for large scale networks
CBDAS [26]	Nonprobabilistic	Distributed	(i) Energy efficiency is achieved through cycle head, as only one is responsible for sending data of the entire network	(i) In a long chain, far away nodes might be selected as CH resulting in high energy consumption (ii) It has chain breakage due to suboptimal CH (iii) Cycle head selection is based on only residual energy
DUCA [27]	Random	Distributed	(i) Even distribution of cluster heads (ii) Decreasing the differences in the cluster sizes though identifying overlapped regions	(i) CH selection being based on random number might lead to suboptimal CH (ii) It is not suitable for mobile nodes and large scale networks
Grid and genetic algorithm [28]	Nonprobabilistic	Distributed	(i) Optimal CH selection (ii) Energy efficient	(i) Periodic calculations and dynamic changes of clustering midpoints increase network overhead
PBDAS [29]	Random/nonprobabilistic	Distributed	(i) It improves network performance (ii) Only chain head is responsible for sending data to BS; the rest of cell heads will be in sleep mode	(i) Suboptimal CH can cause chain breakage (ii) The initial selection is random and thus can lead to suboptimal CH. (iii) It is not suitable for large scale networks due to large chains
Grid sectoring [30]	Nonprobabilistic	Hybrid	(i) Energy efficient (ii) Even distribution of load	(i) CH selection is based on only one parameter that is the distance from the centroid (ii) It might have isolated nodes which can lead to network partitioning
GBRR [12]	Nonprobabilistic	Distributed	(i) Adaptive approach (ii) Suitable for large scale randomly deployed sensor nodes	(i) Far away nodes might lead to suboptimal CH (ii) It can have grids having no node
CH using ANP [31]	Nonprobabilistic	Hybrid	(i) Optimum CH selection (ii) Achieves energy efficiency and extends overall network lifetime (iii) Parameters prioritization	(i) The mobility of nodes is not considered, applied on static nodes (ii) For large scale network, computational overhead will increase
Randomized grid-based approach [32]	Hybrid	Hybrid	(i) Energy efficient (ii) Optimum number of CHs (iii) Suitable for defined small scale networks	(i) There is computational overhead if active nodes do not satisfy the coverage area (ii) The percentage is calculated again for nodes that are not redundant nor active, leading to extra energy consumption (iii) It is not suitable for large scale networks

6. Conclusion

Wireless Sensor Networks (WSN) are gaining more attention due to their low cost, small size, and battery powered sensor nodes for capturing and monitoring harsh geographic areas. The sensor devices are integrated with other technologies such as IoT, mobile phones, IEEE 802.11, and much more, which makes WSN one of the significant technologies of the 21st century. Due to the hostile operating environment and scarce battery resource wireless sensor networks are a challenging area of research. This paper has attempted to provide a comparative analysis of existing schemes of sensor node deployment and energy efficient clustering protocols with their relative importance and limitations.

As WSN is resource constrained and often operates in an unattended environment, therefore battery replacement or recharging is not possible. In order to wisely use the battery source, various energy efficient protocols have been discussed. Out of these energy efficient schemes, cluster-based schemes have received relatively great interest due to the significant gains in overall network life time. In most of the existing techniques, various attempts have been made to achieve energy efficiency through hierarchical clustering where nodes are grouped into clusters and data is forwarded by the cluster head to base station (BS). In this work, state-of-the-art energy efficient cluster-based and grid-based techniques in WSN have been critically evaluated taking into account different parameters like metric for cluster formation, energy consumption, and network lifetime. Moreover, the design issues and research challenges of hierarchical approaches have been discussed. On the basis of the evaluation metrics, a comparative analysis is presented that can help in selection of appropriate technique for specific requirements. The significance of both clustering and grid-based techniques and their limitations have been identified giving the notion about the applicability of a particular scheme in a certain operating environment.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] N. A. Pantazis, S. A. Nikolidakis, and D. D. Vergados, "Energy-efficient routing protocols in wireless sensor networks: a survey," *IEEE Communications Surveys & Tutorials*, vol. 15, no. 2, pp. 551–591, 2013.

[2] D. Jia, H. Zhu, S. Zou, and P. Hu, "Dynamic cluster head selection method for wireless sensor network," *IEEE Sensors Journal*, vol. 16, no. 8, pp. 2746–2754, 2016.

[3] N. Sabor, S. Sasaki, M. Abo-Zahhad, and S. M. Ahmed, "A comprehensive survey on hierarchical-based routing protocols for mobile wireless sensor networks: review, taxonomy, and future directions," *Wireless Communications and Mobile Computing*, vol. 2017, Article ID 2818542, 23 pages, 2017.

[4] K. P. Sharma and T. P. Sharma, "Energy-hole avoidance and lifetime enhancement of a WSN through load factor," *Turkish Journal of Electrical Engineering & Computer Sciences*, vol. 25, no. 2, pp. 1375–1387, 2017.

[5] C. Chong and S. P. Kumar, "Sensor networks: evolution, opportunities, and challenges," *Proceedings of the IEEE*, vol. 91, no. 8, pp. 1247–1256, 2003.

[6] S. Yinbiao, P. Lanctot, and F. Jianbin, "Internet of things: wireless sensor networks," White Paper, International Electrotechnical Commission, 2014, http://www.iec.ch/whitepaper/pdf/iecWP-internetofthings-LR-en.pdf.

[7] K. Ashton, "That 'internet of things' thing," *RFID Journal*, vol. 22, pp. 97–114, 2009.

[8] J. M.-Y. Lim, Y. C. Chang, M. Y. Alias, and J. Loo, "Cognitive radio network in vehicular ad hoc network (VANET): A survey," *Cogent Engineering*, vol. 3, no. 1, Article ID 1191114, 2016.

[9] F. Wang, L. Hu, J. Hu, J. Zhou, and K. Zhao, "Recent advances in the internet of things: multiple perspectives," *IETE Technical Review*, vol. 34, no. 2, pp. 122–132, 2017.

[10] Z. Wu, E. Jedari, R. Muscedere, and R. Rashidzadeh, "Improved particle filter based on WLAN RSSI fingerprinting and smart sensors for indoor localization," *Computer Communications*, vol. 83, pp. 64–71, 2016.

[11] H. Farman, H. Javed, J. Ahmad, B. Jan, and M. Zeeshan, "Grid-based hybrid network deployment approach for energy efficient wireless sensor networks," *Journal of Sensors*, vol. 2016, Article ID 2326917, 14 pages, 2016.

[12] X. Meng, X. Shi, Z. Wang, S. Wu, and C. Li, "A grid-based reliable routing protocol for wireless sensor networks with randomly distributed clusters," *Ad Hoc Networks*, vol. 51, pp. 47–61, 2016.

[13] S. M. Zin, N. B. Anuar, M. L. M. Kiah, and A.-S. K. Pathan, "Routing protocol design for secure WSN: review and open research issues," *Journal of Network and Computer Applications*, vol. 41, no. 1, pp. 517–530, 2014.

[14] Q. Mamun, "A qualitative comparison of different logical topologies for wireless sensor networks," *Sensors*, vol. 12, no. 11, pp. 14887–14913, 2012.

[15] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proceedings of the 33rd Annual Hawaii International Conference on System Siences (HICSS '00)*, vol. 2, p. 10, January 2000.

[16] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks," *IEEE Transactions on Wireless Communications*, vol. 1, no. 4, pp. 660–670, 2002.

[17] S. Mahajan, J. Malhotra, and S. Sharma, "An energy balanced QoS based cluster head selection strategy for WSN," *Egyptian Informatics Journal*, vol. 15, no. 3, article 101, pp. 189–199, 2014.

[18] G. Y. Park, H. Kim, H. W. Jeong, and H. Y. Youn, "A novel cluster head selection method based on k-means algorithm for energy efficient wireless sensor network," in *Proceedings of the 27th International Conference on Advanced Information Networking and Applications Workshops (WAINA '13)*, pp. 910–915, Barcelona, Spain, March 2013.

[19] J.-M. Kim, S.-H. Park, Y.-J. Han, and T.-M. Chung, "CHEF: cluster Head Election mechanism using Fuzzy logic in wireless sensor networks," in *Proceedings of the 10th International Conference on Advanced Communication Technology (ICACT '08)*, pp. 654–659, Gangwon-Do, Republic of Korea, February 2008.

[20] S. Soro and W. B. Heinzelman, "Prolonging the lifetime of wireless sensor networks via unequal clustering," in *Proceedings*

of the 19th IEEE International Parallel and Distributed Processing Symposium (IPDPS '05), pp. 236–243, Washington, DC, USA, April 2005.

[21] P. Chatterjee and N. Das, "Coverage constrained non-uniform node deployment in wireless sensor networks for load balancing," in *Proceedings of the 1st International Conference on Applications and Innovations in Mobile Computing (AIMoC '14)*, pp. 126–132, Kolkata, India, February 2014.

[22] J. Yu, Y. Qi, G. Wang, and X. Gu, "A cluster-based routing protocol for wireless sensor networks with nonuniform node distribution," *AEU-International Journal of Electronics and Communications*, vol. 66, no. 1, pp. 54–61, 2012.

[23] P. K. Batra and K. Kant, "LEACH-MAC: a new cluster head selection algorithm for Wireless Sensor Networks," *Wireless Networks*, vol. 22, no. 1, pp. 49–60, 2016.

[24] Y. Q. J. Yu, G. Wang, Q. Guo, and X. Gu, "An energy-aware distributed unequal clustering protocol for wireless sensor networks," *International Journal of Distributed Sensor Networks*, vol. 2014, p. 8, 2014.

[25] T. P. Sharma, R. C. Joshi, and M. Misra, "GBDD: grid based data dissemination in wireless sensor networks," in *Proceedings of the 16th International Conference on Advanced Computing and Communications (ADCOM '08)*, pp. 234–240, IEEE, Chennai, India, December 2008.

[26] Y.-K. Chiang, N.-C. Wang, and C.-H. Hsieh, "A cycle-based data aggregation scheme for grid-based wireless sensor networks," *Sensors*, vol. 14, no. 5, pp. 8447–8464, 2014.

[27] R. N. Enam, R. Qureshi, and S. Misbahuddin, "A uniform clustering mechanism for wireless sensor networks," *International Journal of Distributed Sensor Networks*, vol. 10, no. 3, Article ID 924012, 2014.

[28] J. Zeng, "A clustering method of combining grid and genetic algorithm in wireless sensor networks," in *Proceedings of the International Conference on Information Engineering and Applications (IEA) 2012: Volume 3*, pp. 773–779, Springer, London, UK, 2013.

[29] N.-C. W. Y.-K. Chiang and C.-H. Hsieh, "A path-based approach for data aggregation in grid-based wireless sensor networks," in *Proceedings of the National Computer Symposium*, pp. 1–6, Taichung, Taiwan, 2013.

[30] A. Thonklin and W. Suntiamorntut, "Load balanced and energy efficient cluster head election in wireless sensor networks," in *Proceedings of the 8th Electrical Engineering/ Electronics, Computer, Telecommunications and Information Technology (ECTI '11)*, pp. 421–424, Khon Kaen, Thailand, May 2011.

[31] H. Farman, H. Javed, B. Jan et al., "Analytical network process based optimum cluster head selection in wireless sensor network," *PLoS ONE*, vol. 12, no. 7, Article ID e0180848, 2017.

[32] S. Dash, B. P. Nayak, B. S. Mishra, and A. R. Swain, "Randomized grid-based approach for complete area coverage in WSN," in *Proceedings of the IEEE 7th International Advance Computing Conference (IACC '17)*, pp. 307–312, Hyderabad, India, January 2017.

[33] D. Xu and J. Gao, "Comparison study to hierarchical routing protocols in wireless sensor networks," *Procedia Environmental Sciences*, vol. 10, pp. 595–600, 2011.

[34] P. S. Mann and S. Singh, "Energy-efficient hierarchical routing for wireless sensor networks: a swarm intelligence approach," *Wireless Personal Communications*, vol. 92, no. 2, pp. 785–805, 2017.

[35] P. Nayak and A. Devulapalli, "A fuzzy logic-based clustering algorithm for WSN to extend the network lifetime," *IEEE Sensors Journal*, vol. 16, no. 1, pp. 137–144, 2016.

[36] A. Essa, A. Y. Al-Dubai, I. Romdhani, and M. A. Eshaftri, "A new dynamic weight-based energy efficient algorithm for sensor networks," in *Smart Grid Inspired Future Technologies: First International Conference, SmartGIFT 2016, Liverpool, UK, May 19–20, 2016, Revised Selected Papers*, pp. 195–203, Springer International Publishing, Cham, Switzerland, 2017.

[37] P. Kumarawadu, D. J. Dechene, M. Luccini, and A. Sauer, "Algorithms for node clustering in wireless sensor networks: a survey," in *Proceedings of the 4th International Conference on Information and Automation for Sustainability (ICIAFS '08)*, pp. 295–300, Colombo, Sri Lanka, December 2008.

[38] L. Kong, Q. Xiang, X. Liu et al., "ICP: instantaneous clustering protocol for wireless sensor networks," *Computer Networks*, vol. 101, pp. 144–157, 2016.

[39] J. Yuea, W. Zhang, W. Xiao, D. Tang, and J. Tang, "Energy efficient and balanced cluster-based data aggregation algorithm for wireless sensor networks," *Procedia Engineering*, vol. 29, pp. 2009–2015, 2012.

[40] S. Ozdemir and Y. Xiao, "Secure data aggregation in wireless sensor networks: a comprehensive overview," *Computer Networks*, vol. 53, no. 12, pp. 2022–2037, 2009.

[41] M. M. Afsar and M.-H. Tayarani-N, "Clustering in sensor networks: a literature survey," *Journal of Network and Computer Applications*, vol. 46, pp. 198–226, 2014.

[42] A. A. Abbasi and M. Younis, "A survey on clustering algorithms for wireless sensor networks," *Computer Communications*, vol. 30, no. 14-15, pp. 2826–2841, 2007.

[43] G. Gupta and M. Younis, "Fault-tolerant clustering of wireless sensor networks," in *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC '03)*, pp. 1579–1584, IEEE, New Orleans, La, USA, March 2003.

[44] N. P. Mahalik, *Sensor Networks and Configuration*, Springer, 2007.

[45] B. Mamalis, D. Gavalas, C. Konstantopoulos, and G. Pantziou, "Clustering in wireless sensor networks," in *RFID and Sensor Networks: Architectures, Protocols, Security and Integrations*, Y. Zhang, L. T. Yang, and J. Chen, Eds., pp. 324–353, 2009.

[46] A. Nayyar and A. Gupta, "A comprehensive review of cluster-based energy efficient routing protocols in wireless sensor networks," *International Journal of Research in Computer and Communication Technology*, vol. 3, pp. 104–110, 2014.

[47] Y. Yu, B. Krishnamachari, and V. K. Prasanna, "Issues in designing middleware for wireless sensor networks," *IEEE Network*, vol. 18, no. 1, pp. 15–21, 2004.

[48] H. Huang and J. Wu, "A probabilistic clustering algorithm in wireless sensor networks," in *Proceedings of the 62nd Vehicular Technology Conference*, pp. 1796–1798, September 2005.

[49] A. Youssef, M. Younis, M. Youssef, and A. Agrawala, "Wsn16-5: distributed formation of overlapping multi-hop clusters in wireless sensor networks," in *Proceedings of the IEEE Global Telecommunications Conference (GLOBECOM '06)*, pp. 1–6, December 2006.

[50] A. K. Tripathy and S. Chinara, "Evolution of virtual clustering," in *Wireless Sensor Networks: From Theory to Applications*, 2013.

[51] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," *Computer Networks*, vol. 52, no. 12, pp. 2292–2330, 2008.

[52] M. O. Farooq, A. B. Dogar, and G. A. Shah, "MR-LEACH: multi-hop routing with low energy adaptive clustering hierarchy,"

in *Proceedings of the 4th International Conference on Sensor Technologies and Applications (SENSORCOMM '10)*, pp. 262–268, Venice, Italy, July 2010.

[53] M. Tong and M. Tang, "LEACH-B: an improved LEACH protocol for wireless sensor network," in *Proceedings of the 6th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM '10)*, pp. 1–4, Chengdu, China, September 2010.

[54] H. Al-Refai, A. Al-Awneh, K. Batiha, A. A. Ali, and Y. M. E. Rahman, "Efficient routing leach (ER-LEACH) enhanced on leach protocol in wireless sensor networks," *International Journal of Academic Research*, vol. 3, 2011.

[55] V. Torkzaban, S. Rahmani, and M. Dehghan, "An ID-based routing protocol for WSN," in *Proceedings of the 1st South Central Asian Himalayas Regional IEEE/IFIP International Conference on Internet (AH-ICI '09)*, November 2009.

[56] N. Nokhanji, Z. M. Hanapi, S. Subramaniam, and M. A. Mohamed, "A scheduled activity energy aware distributed clustering algorithm for wireless sensor networks with nonuniform node distribution," *International Journal of Distributed Sensor Networks*, vol. 10, no. 7, Article ID 218678, 2014.

[57] M. R. Majma, H. Pedram, and M. Dehghan, "IGBDD: Intelligent grid based data dissemination protocol for mobile sink in wireless sensor networks," *Wireless Personal Communications*, vol. 78, no. 1, pp. 687–714, 2014.