

Review Article

Intelligent Optimization of Wireless Sensor Networks through Bio-Inspired Computing: Survey and Future Directions

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This survey article is a comprehensive discussion on Intelligent Optimization of Wireless Sensor Networks through Bio-Inspired Computing. The marvelous perfection of biological systems and its different aspects for optimized solutions for non-biological problems is presented here in detail. In the current research inclination, hiring of biological solutions to solve and optimize different aspects of artificial systems' problems has been shaped into an important field with the name of bio-inspired computing. We have tabulated the exploitation of key constituents of biological system for developing bio-inspired systems to represent its importance and emergence in problem solving trends. We have presented how the metaphoric relationship is developed between the two biological and non-biological systems by quoting an example of relationship between prevailing wireless system and the natural system. Interdisciplinary research is playing a splendid contribution for various problems' solving. The process of combining the individuals' output to form a single problem solving solution is depicted in three-stage ensemble design. Also the hybrid solutions from computational intelligence-based optimization are elongated to demonstrate the emergent involvement of these inspired systems with rich references for the interested readers. It is concluded that these perfect creations have remedies for most of the problems in non-biological system.

1. Introduction

After exhaustive effort in gaining maximum productivity from brainstorming solutions, researchers are now inclining towards biologically inspired solutions. Each and every creation of the One has the invitation to the researchers and thinkers to ponder. This creation is perfect in its own life and needs. The ultimate ideological convergence of scientists to this perfect creation for finding the relevant traces of problems and their solutions is in fact moving to "the best." Giving insight attention to the nature and the creation gives the glow to thoughts due to its miraculous architecture. Ibn al-Haitham, a 10th-century mathematician, astronomer, and physicist, invented the first pin-hole camera by understanding the mechanism that light enters the eye, rather than leaving it [1]. In the 9th century, Abbas ibn Firnas was the first person to make a real attempt to construct a flying machine and fly. He designed a winged apparatus, roughly resembling a bird costume [2]. Moreover, Newton's theory of gravity, Wright brothers' influenced work of flying, Einstein's

theory of relativity, and John von Neumann's abstract model of self-reproduction are just the names of few. The intense exploitation of these miraculous creations of the One in Human's problems solving has now organized as a complete field naming biological-inspired computing. The word computing encompasses the activities of using and improving the computer technology, computer hardware, and computer software. The technique of formulating the views, ideas, technologies, and algorithms for unknitting the issues as well as introducing the innovation in computer technology, hardware, and software that are motivated by the biological systems is called biologically inspired computing or bio-inspired computing. Its typical consortium is shown in Tables 1 and 2. Three key subfields are loosely knit together to form the core of bio-inspired computing which are connectionism, social behavior, and emergence. Though biological systems exhibit complex, intelligent, and organize behavior, they are comprised of simple elements governed by simple rules. It is highly cost effective to hire the complex and in-networked processing-based simple rules in man-made systems. The real

effort that comes in this synergistic solution is in finding the similar patterns of issues in artificial (man-made) and real (natural) creation and later their solutions. This invites the interdisciplinary research which is an essential driver for innovation.

The rest of the paper is organized as follows. Section 2 summarizes the intelligent optimization in biological systems. Bio-inspired intelligent optimization for non-biological system is discussed in Section 3. Section 4 shows the optimization in wireless sensor networks' domain. In continuation to this, in Section 5 a connection is tried to be established between real and artificial systems to show how different artificial systems have been developed from the real system and what are the constituents of this establishment. Solution of various problems from the wireless sensor networks' domain from different bio-inspired systems is discussed and tabulated in Section 6. Future direction and conclusion are given in the subsequent sections.

2. Intelligent Optimization in Biological Systems

The real creation of any natural system has marvelous traits in it. The source of inspiration is the traits which provide a guiding light to lead us towards the optimal solution for inspired systems. As the traditional optimization problems need more memory and computational power and are directly exponentially related with the problem size, optimization can be an interdisciplinary approach for finding the best solution of a problem among alternatives. Better computer systems and improved performance of computational tasks such as flexibility, adaptability, decentralization, and fault tolerance can be achieved in the form of bio-inspired algorithms from the principles evolved from Nature. As far as modeling of a problem with respect to the bio-inspired algorithms is concerned it enables the problem to solve according to the principles evolved from nature by understanding nature's rule the complex problems. Figure 1 below shows the optimization techniques classification to solve optimization issues based on three categories, that is, search space, problem, and form of objective function.

One of the key features of biological systems in searching the best solution is optimization. Most of the time, optimization process needs iteration of working sessions. Foraging behavior in ants and bees systems, flocking, herding, and schooling process in birds, animals, and fish, respectively, are some of the typical examples of iteration of working sessions for the optimal respective solutions. Optimization is the scientific discipline that raises the winning flag for the solution which gives the optimal result among all available alternatives in resolving the particular problem. Swarm intelligence (SI) is one of the aspiring solutions from bio-inspired computing for such heuristic optimization problems, for example, routing. Swarm refers to the large no. of insects or other small organized entities, especially when they are in motion. Global intelligent behavior to which the individuals are entirely unknown is emerged due to the local, self-organized, and decentralized interaction of swarm's agents.

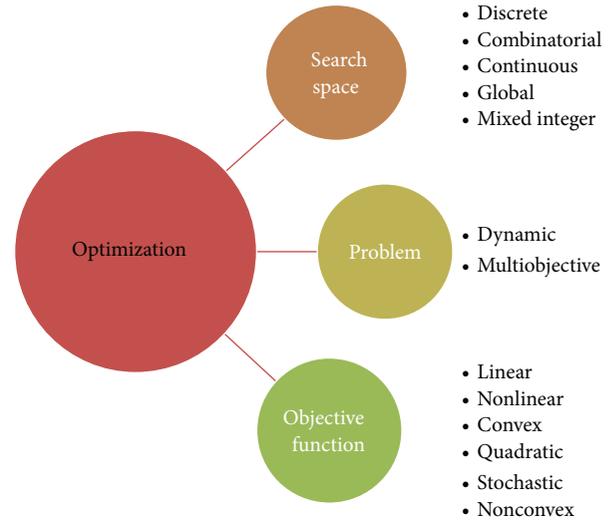


FIGURE 1: Optimization categories.

Natural examples of SI include ant colony, bird flocking, animal herding, bacterial growth, fish schooling, drop water, and fireflies. Examples of algorithms under the head of SI are Ant Colony Optimization (ACO), River Formation Dynamics (RFD), Particle Swarm Optimization (PSO), Gravitational Search Algorithm (GSA), Intelligent Water Drop (IWD), Charged System Search (CSS) and Stochastic Diffusion Search (SDS). Among all genus under swarm intelligence, autonomously social and extremely well-organized as well as colony-based life is of Ants. Inspired algorithm from ants is Ant Colony Optimization. Number of combinatorial optimization problems are targeted by the ACO technique such as asymmetric travelling salesman [3], graph coloring problem [4], and load balancing in telecommunication networks [5]. Ant Colony Optimization has been formalized into a meta-heuristic for combinatorial optimization problem. A meta-heuristic is a set of algorithmic concepts that can be used to define heuristic methods applicable to wide set of different problems. Examples of meta-heuristic include tabu search [6–8], simulated annealing [9, 10], iterative local search [11], evolutionary computation [12–15], and ant colony optimization [16–19]. For their applications in different fields for the optimal solutions, their nature is customized accordingly. For example, in case of Wireless Sensor Network (WSN), which is an energy, memory, and computational power constraint network, the proposed heuristic algorithm must be customized enough to cater for these constraints.

3. Bio-Inspired Intelligent Optimization for Nonbiological System

Survival of the best is the key driving force behind the optimization in artificial systems. From nothing to existence of global village clearly portrays this endeavor of moving to "the best." The influence of biology and life sciences is a source of inspiration since ages, as the design of aircraft leads to be inspired from birds, the fighter jet planes from

TABLE 1: Optimization in wireless sensor networks' domain.

Optimization problem	WSN challenges	Objectives of optimization problems in WSN
Multiobjective [20]	Design and deployment	Multitude objectives of deployment/design issues of WSN like coverage, differential detection levels, lifetime of node, energy-related parameters, energy efficiency, sensing point uniformity, and number of sensors which needs to be optimized simultaneously or optimal tradeoff is required between objectives.
Multidimension [24]	Localization	Deals with position estimation, signal propagation time, and the received signal strength of which at least one nonlinear function needs to be optimized.
Combinatorial [23]	Security	Searching for optimal solution from discrete variables of the functions like node capabilities, possible inside threats, integrity, end-to-end data security, and key distribution for the best solution.
Multi objective [21]	Routing and clustering	Multitude objectives of routing and clustering of WSN like energy consumption, network delay, and data packet lost rate, helps relay the sensed data traffic to the sink, which needs to be optimized simultaneously or optimal tradeoff is required between objectives.
Combinatorial [25]	Data aggregation	The optimal solutions may be discrete or it may be discrete solution like efficient collection of sensed data, forwarding data to base station, and integrating data derived from multiple sources for the best solution.
Multi objective [22]	Scheduling and MAC	Multitude objectives passive mode, active mode, and transmission of data by node for maximum life time by conserving energy, which needs to be optimized simultaneously or optimal tradeoff is required between objectives.
Combinatorial [26]	QoS management	The optimal solutions may be discrete or it may be discrete solution like analytically plan and allocate resources for the best solution.

TABLE 2: Exploitation of key constituents of biological systems for developing bio-inspired systems.

Key constituents of biological system	Examples of constituents	Bio-inspired system
Cell	Structural unit	- DNA computing [27] - Membrane computing [28] - Cellular automata [29] - Rendering [30]
Organ	- Arteries - Bronchi - Ears - Heart - Circulatory system - Digestive system - Nervous system	- Sensor network [31] - Excitable media [32]
Organ system	- Reproductive system - Respiratory system - Skeletal system - Urinary system	- Artificial neural system [33] - Artificial immune system [34] - Genetic algorithm [35] - Biological fault tolerant [36]
Organism	- Animals - Plants - Protists - Bacteria	- Fractal geometry [37] - Lindenmayer system [38] - Morphogenesis system [39] - Artificial life [40]
Ecosystem	Biological system and its physical environment	- Biodegradability production [41] - Emergent systems [42] - Communication network and protocol [43]

birds of prey, commercial jet planes from the birds that travel long distances, submarines and other deep sea diving machines from deep sea fish, surgical tools from beaks of various birds, helicopters from dragon flies, Bionic arms, and muscles from human arm and muscles. The effort in terms of time and space of finding the optimal solution depends on application, search space and solution required optimality level. The alternative prospective feasible solutions of that

specific problem are reduced if the constraints are posed by the user or the problem itself.

The constraints usually restrict the search space. The presented problems where the constraints are absent are called it unconstrained optimization. In contrast to constraint optimization problem where the limits and boundaries are defined, global optimization problems is concerned with the detection of optimal one. This is not always possible or

necessary indeed. There are cases where suboptimal solutions are acceptable depending on their quality compared to the optimal one. This is usually described on local optimization. Conventional approaches exist to achieve the better solutions but the research is now inclining towards the bio-inspired intelligent optimization techniques. Artificial Neural Network (ANN) is a massively parallel computing systems consisting of large number of interconnected simple processors to handle various types of challenging computational problem such as in wireless sensor network, RF and microwave communication, Radar communication, and Antenna and wave propagation. This aspiring system is based on the organizational principles used in humans. Rendering/computer graphics technology is inspired by the pattern of animal skins, bird feathers, bacterial colonies, and mollusk shells which have their applications in pattern recognition, wireless sensor network, and others. Similarly, inspiration of artificial immune system by natural immune system, fractal geometry by clouds, river networks, and snowflakes are some examples of it. The next section clearly intuites the emergence of bio-inspired solution for the optimization in various applications of wireless sensor network.

4. Optimization in Wireless Sensor Networks' Domain

In most of the real-world problems, an optimal solution for simultaneously satisfying the one or more conflicting performance attributes is required. The key in seeking the optimization in solution for such type of problems is setting tradeoff among the participating attributes in their solutions. For example, in aircraft design, tradeoff is set between minimizing the fuel consumption and maximizing its performance, and real-time communication of sensed data from source to destination, the congestion, packet drop and the energy consumption are also minimized as the participating attributes. In [20–22], Authors have targeted the wireless sensor networks' domain for the optimization of multitude objectives in design and deployment, routing and clustering, and scheduling and MAC aspects. In [20] the author has analyzed the major challenges in designing wireless sensor network. He has presented the multiobjective deployment of nodes with establishing the tradeoff between the desired and contrary requirements for coverage, differentiated detection levels, network connectivity, network life time, data fidelity, energy efficiency, number of nodes, fault tolerance, and load balancing.

He has also purposefully discussed the need for simultaneous optimization of the aforementioned objectives. Wei and Zhi [21] have introduced an advanced ant colony algorithm based on cloud model (AACOCM) for the optimization of multitude aspects of achieving optimal routing. This multiobjective optimization model optimizes the functions such as energy consumption, network delay, and data packet loss rate. Various services having different energy, cost, delay, and packet loss requirements can be focused by tuning the weight of each function of this proposed model. Passive mode, active mode, and transmission of data by node for

maximum life time by conserving energy are the multitude objectives that are focused in [22], which needs to be optimized simultaneously or optimal tradeoff is required between these objectives for the purpose of achieving better scheduling and accessing the media at MAC layer.

In Combinatorial Optimization (CO) some or all of the participating objects or variables are discrete or restricted to be integral. The target in CO is to find an optimal object where finite objects are available. Vehicle Routing Problem (VRP), Travelling Salesmen Problem (TSP), Minimum Spanning Tree (MST) problem, and data routing in WSN are its typical examples. Tie and Li [23] have introduced a security key management scheme which is based on combinatorial optimization. The results come up with yielding optimal results for the number re-key messages. The ultimate target is to search for the optimal solution for discrete variables of the function like node capabilities, possible inside threats, integrity, end-to-end data security, and key distribution for the best solution.

5. From Real to Artificial

Some of the things are similar to each other at some important aspect even of their opposed nature. A desktop computer is a scooped-out hole in the beach where information from the cyber sphere wells up like sea water is a typical example of developing similarity between non alike things. But the key in making such relationship needs to explore the nature of two comparing systems. In the following paragraphs, Ant as a typical example of biological system is explored with respects to the basic constituents of biological systems. The foraging behavior of Ants is taken to develop the relationship with the routing in Wireless Sensor Networks. A typical representation of ACO algorithm with respect to Ants foraging behavior is shown in Figure 2.

The constituents of biological systems which forms the basis for developing metaphoric relationship to artificial system are cell (structural unit), organs (cell joins to form tissues and tissues joins to form a functional body), organic system (functional body interacts to work for same task), organism (multiple organic systems join to form a complete structure), and ecosystem (environment interacting to the complete structure). The perfection of the real system from unit to system is reflected in Table 2 by showing the emergence of these components for the exploitation in developing inspired systems. Many complete research fields inspired by the constituents of biological system have been established, which have their key roles in optimizing the solution for various problems in non-biological systems. The indispensable role of bio-inspired solutions in variety of applications for their optimized solution is demonstrated in the subsequent paragraphs.

Architecture in interlinking of individuals matters a lot in building the power of unity. In case of centralized systems reliable, effective, and efficient coordination to the central hub is indispensable. Death of central point is the end of the system. In contrast to it, decentralized architecture needs powerful autonomous entities on one hand, and

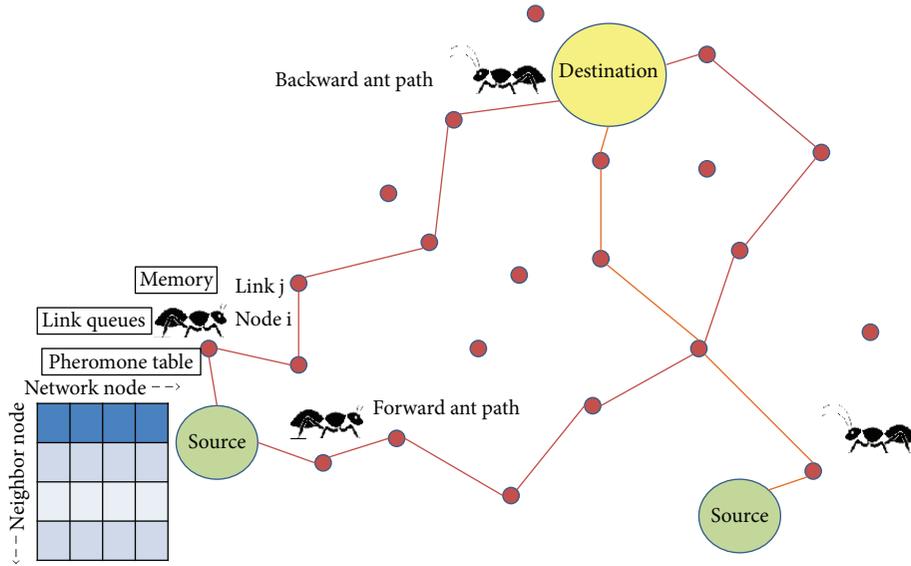


FIGURE 2: Representation of ACO Algorithm With Respect to Ants Foraging Behavior.

TABLE 3: Application of bio-inspired systems in wireless sensor network.

Inspired systems	Natural systems	Wireless sensor network application(s)
Artificial neural network [33]	The brain	Power efficiency [44], fault detection [45], self-configuration [46]
Artificial immune network [34]	Immune system [47]	Misbehavior detection [48], image pattern recognition [49]
Genetic algorithm [35]	Natural evolution system	Dynamic shortest path routing [50], lifetime maximization [51]
Cellular automata [29]	Life Life like/ game of life	Large network simulations [52], area coverage scheme [53]
Rendering (computer graphics) [30]	Patterns of animal skins, birds feathers, mollusk shells, and bacterial colonies [54]	Range-free localization [55]
Fractal geometry	Clouds, river networks, snowflakes, cauliflower or broccoli, and systems of blood vessels and pulmonary vessels, ocean waves	Antenna designing [56]
Communication networks and protocols	Epidemiology	Cross-layer communication protocol [57, 58], underwater communication [59]
Excitable media	Forest fires, wave, heart condition	Designing of intelligent sensor systems [60]
Sensor network	Sensory organs	Self-configuration [61], target tracking [62]

then it also reflects the behavior of adaptation (flexible to changing environment), self-assembly (unit to be one), self-organizing (interaction for the one), and self-regulation, (keeping the process tunably smooth) [25] as in WSN due to the distributed knowledge, distributed control and scalable properties on the other hand. Although the architecture is application dependent, decentralized system has variety of advantages over the centralized system. The real creation of the One also exhibits such fascinating behavioral and architectural traits to which Brownlee has pointed out in [71]. He has quoted architectural and behavioral characteristics in biological system with referring to Lodding and Nas [72]

and Marrow [73]. Typical behavioral traits are adaptation, autonomous, fast and appropriate solutions in the short term, specific and optimized solutions in the long term, memory, self-assembly, self-regulation, and self-organization, learning, and intelligence. This is in parallel to architectural traits in natural systems such as decentralized control, distributed knowledge, emergent behavior dynamic, fault and noise tolerant, flexibility, parallel processing, persistent, robustness, and scalability. Insight study in finding the similar traits is the prerequisite to develop the metaphoric relationship between the two natural and artificial systems. Iram et al. [74] have discussed the above-mentioned traits in the context

of developing the metaphoric relationship between the two systems.

6. Wireless Sensor Networks and Bio-Inspired Systems

In this section, we have taken Ant Colony Optimization inspired by Ant System (AS) from the biological field and WSN from the artificial systems to understand the metaphoric relationship between the natural and artificial systems. Firstly, we have bridged the gap between the two technologies by finding similar traits. Then foraging behavior of ants and the routing behavior in WSN are analyzed to develop their metaphoric relationship.

In AS there is no central dictation for the target and even of the next goal. Rather stigmergic communication through pheromone is the only source dictating the ants for any action, that is, foraging, invading, security, mating, migration. Ants are distributed on the field and follow each other through the traces of pheromone trails. If ants are considered vertices then the pheromone trails between them represent the edges forming a graph theoretical problem. Due to the decentralized and distributed nature of ants in foraging between the source and destination, the algorithmic complexity of their foraging behavior (routing) turns to the worst case of $O(2^n)$, that is, exponential making it an NP hard problem as their first time exact and optimal solution is almost impossible. This meta-heuristic nature of foraging behavior's solution needs recursion of searching process for optimal result. Complete participation of Ant's swarm with multi-objectives of rich food source, shortest and safe path, making the foraging process collectively as multi-objective combinatorial optimization problem.

Among the wireless networks, wireless sensor network is the most emerging and multiconstraint (energy, memory, and computational as well as bandwidth) technology. There also come up some differences from the traditional wireless networks like cellular network and especially from its close ancestor, ANet (Ad hoc Network) like in-attendant operation for a long period in the energy constraint environment, densely and randomly deployed nodes, high node failure, and other constraint resources. WSN has its applications in wildlife monitoring, cold chain monitoring, Glacier monitoring, rescue of avalanche victims, cattle herding, geographical monitoring, monitoring of structures, vital sign monitoring, ocean water and bed monitoring, monitoring of fresh water quality, tracking vehicles, sniper localization, volcano monitoring and tunnel monitoring, and rescue. Underwater sensor network, that is typically based on ultrasound, is also a key application of WSN [75, 76]. Some of the real-world projects of wireless sensor networks are Bethymetry [77], Ocean Water Monitoring [78], ZebraNet [79], Cattle Herding [80], and Bird Observation on Great Duck Island [81], Grape Monitoring [82], Rescue of Avalanche Victims [83], and neuRFon [84].

In wireless sensor network, nodes are uniformly or stochastically deployed in the target region. Interconnection of nodes in a decentralized fashion without following

any preexisting infrastructure is named as AdHoc network. In wireless sensor network, nodes are scattered randomly across the region for decentralizing the network traffic and computational load to increase the coverage, capacity, and reliability. This distributed network scenario also comes up with avoidance of single point of failure. As every node in WSN either acts as sensor, router, or gateway node which has its own computing responsibilities resulting in distributed computing paradigm, uniform or stochastic deployment of wireless sensor nodes comes up with a distributed architecture of nondirected graph where nodes are vertices and the edges represent the communication link between them. In the distributed network of sensor nodes, each computational autonomous entity (node) acts/can act as a sensor as well as router.

This entity establishes communication links with other node in its footprint through omnidirectional full duplex antenna. This cooperative interaction of neighboring nodes expands up to the whole network giving birth to its self-configuring, self-organizing, self-adaptive, and self-synchronizing capabilities. These are extensively exploited by routing algorithms for catering the dynamicity of mobile ad hoc sensor nodes. In computational complexity theory, optimization problem of routing is a special type of computational problem which is concerned with the issues of repetition of algorithmic process until an optimal solution is reached or the required target is met. As the very nature of routing is NP complete (nondeterministic complete) in its optimal solutions search, so resolving such problems in polynomial time is nondeterministic and hence the nature of their solutions is heuristic as such problems cannot always have the definite required solutions. From the case of meta-heuristic solutions of Ant Colony Optimization for its suitability to Mobile Ad hoc Network (MANET), Mehfuz and Doja [85] have described the following reasons; that is why ACO meta-heuristic could perform well in multi-hop scenario of MANET.

- (i) *Dynamic Topology*. ACO meta-heuristic is based on agent systems and works with individual ants.
- (ii) *Local Work*. ACO meta-heuristic is based on local information that is, no routing table and other information, blocks have to be transmitted to neighbors.
- (iii) *Link Quality*. Agent movement updates the link and its quality.
- (iv) *Support for Multipath*. Due to pheromone concentration value of neighbor nodes at some specific nodes, this also supports multipath.

Apart from the emergence of bio-inspired solutions in artificial systems in general as is intuited from Table 3, it has a lot of contributions in the intelligent optimization of variety of applications in wireless communication domain specifically. Table 3 shows the list of inspired systems originated from the natural system and their application in WSN domain. References are also cited for the further exploration of interested topics. Without exaggeration, it can be concluded that there is no field, which is left uninspired

by natural behavior. In contrary to this emergence of bio-inspired solutions, Abbott [86] have pointed out the failure of bio-inspired computing to mirror the biological realities. He concluded that these failures arise out of our inability as yet to fully understand what is meant by emergence. But the fact is that bio-inspired computing has the remedies for most of the problems in non-biological systems. As a proponent of this concept, he concluded his article with the claim that bio-inspired computing should be 99% inspiration combined with 1% mimicry. This is the inverse of Thomas Alva Edison's point of view that described invention as 1% inspiration and 99% perspiration. So far as the biological inspiration in the field of network routing esp. mobile wireless sensor network is concerned, there is well established history of this relation in different aspects [87–89].

7. Future Directions

Interdisciplinary research is playing a splendid contribution for various problems' solving. Even the fields those are ever, not only seemed to be very angry to each other but also considered to be on rivalry, have now become indispensable to each other. Computational biology and econometrics are some of those examples. Within the nature, intradisciplinary research of merging the different biological systems is coming up on the scene to further improve the solutions presented earlier by single biological systems. Ideas from cellular automata are merging to genetic algorithms to present new and improved solution to variety of problems [90]. This synergistic mating of biological systems is further needed to figure out the consequences of individual artificial system concocted with other artificial system. This results in improving the algorithms in many dimensions and its applications in various disciplines thus forming ensemble systems.

The design of ensembles can be viewed as a three-stage process: generation of a pool of candidates, selection of some of them from this pool, and combination of the individual outputs to produce a single output that is, a unique solution to a complex problem [91]. This three-stage ensemble process is shown in Figure 3. Although there are no hard and fast rules to make biological hybrid solutions for any type of non-biological problem, the merger of various techniques depends upon the targeted problem and the way the researcher wants to solve it.

Moreover, the effectiveness of the biological solution to solve various artificial problems depends upon the type and scale of the problem.

So to present even a summarized view depicting the relationship between various biological systems and non-biological problems may require more numbers of volumes. Routing issue is solved best by SI as it deals with adaptive, robust, scalable, and distributive properties. A variety of algorithms are involved in SI, that is, fish schooling, bee colony, and ACO algorithms. ANN, GA, and PSO are centralized solutions. ANN and GA have comparable longer run time. The hybrid approach, that is, using multi-classes of CI complement more for high level of optimization which is

a future path way for the researcher's as the hybrid approach is lean manufacturing idea, convinced the cerebral drama to have a look to the other side of the picture for better optimization. FL is deterministic and fast as compared to other algorithms but optimization is an issue in it. AIS deals with very little solutions of WSN as it is a better tool than GA but computationally requires more run time. Hence, it is intuited from the above discussion that if a technique is strong in one aspect then on the other hand its other aspect is weak. To make the life easy, we are presenting the core characteristics of some of the biological systems, those come under the umbrella of CI. From the given tabulated view of evaluating parameters and the efficiency of biological techniques against those parameters in Table 4, the researcher can select the appropriate technique or make a hybrid technique out of it to better solve the non-biological problem. For this implication, the nature and characteristics of targeted problem should be carefully identified to get them solved by the selected individual or hybrid biological technique. State variables, not of search points, running time, target problem, and features are efficient to compare and analyze CI paradigm algorithms to solve WSN issues. It can also be applied to a variety of fields to optimize and solve the issues of different application fields of CI. These are all helping to optimize a certain problem. Table 4 shows a comparative analysis of each CI paradigms algorithms. A detailed discussion and description of the evaluation parameters mentioned in it is given in [94]. It also shows that these all will help the researchers to optimize any issue in any field.

Under the artificial systems perceptive, in Figure 4 there are few systems which are enhancing each other's specifications and applications to enhance the traits of one artificial system by using the traits of another artificial system. We can simplify more problems by admiring the traits of artificial systems of this computational modern era. The hybrid algorithms from the intradisciplinary domain of computational intelligence are also a very useful approach and gaining fame for solving the computational problems by integrating the two or more algorithms of this paradigm. The crux of advantages gaining from this merger conclude in a point that the hybrid algorithm formed is capable to eliminate the weakness of one algorithm and polishes the benefits of other algorithms for solving the relevant issue which cannot be solved more efficiently with one algorithm of this solution domain.

The examples of such hybrid computational intelligence algorithms are evolutionary swarm intelligence, Swarm-based Fuzzy Logic Control, Genetic Algorithm-Neural network, genetic-fuzzy intelligence, neuroFuzzy Technique, PSO-Genetic Algorithm, and Neuro-Immune Systems. These hybrid systems are also used in wireless sensor networks domain.

Table 5 shows few of the issues of WSN which are solved by hybrid algorithms of CI. The Neuro fuzzy algorithm [68] optimizes the clustering issue by passing the parameters of each sensor nodes such as memory, available power, and processing speed of each sensor nodes. These inputs are mapped to the fuzzy logic's set of rules to achieve functional objectives, so that the output actions are verified

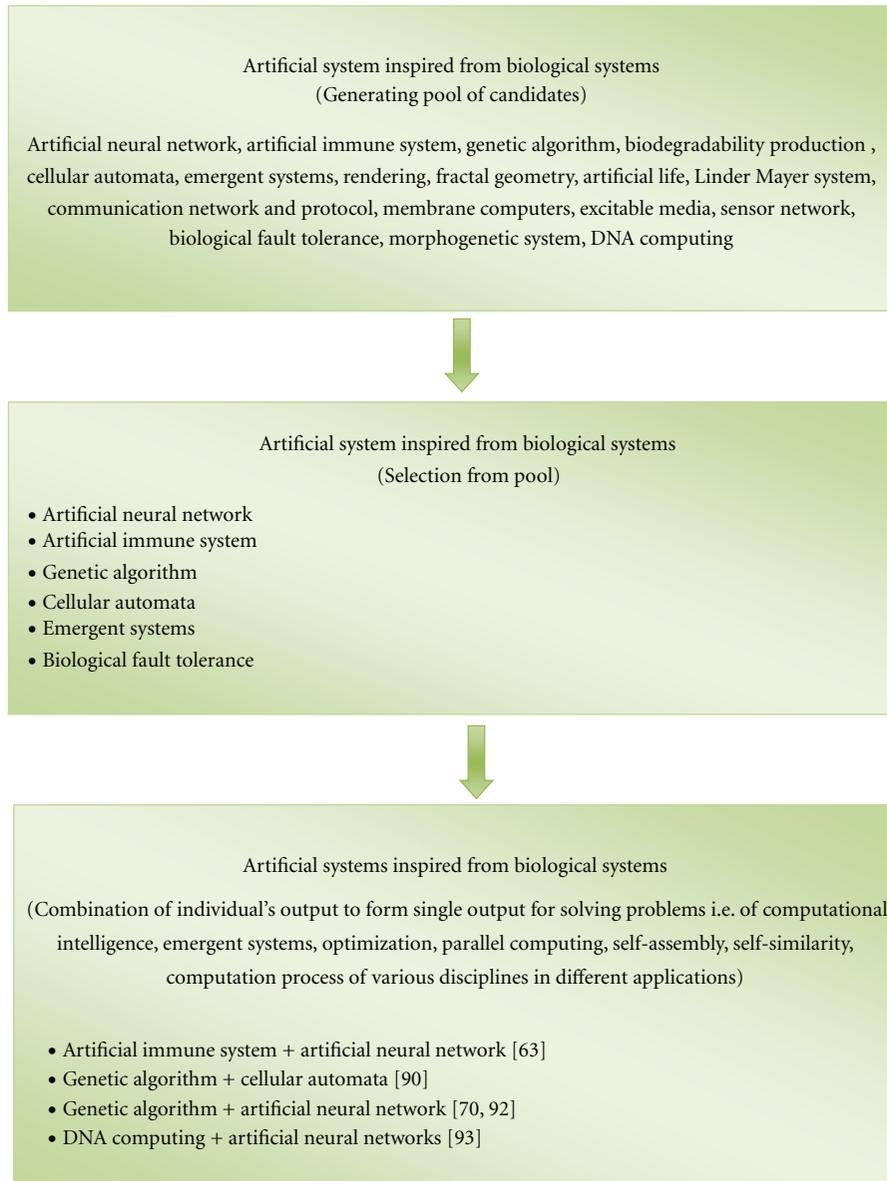


FIGURE 3: Three stage process of ensembles design.

and optimized against the input information. The output of fuzzer is monitoring coefficients for each node. It depends on power availability, memory availability, and processing speed of sensor node. Finally, input the monitoring coefficients to the neural network to obtain clustering depending on the application requirement.

Similarly Yanjing and Li [67] optimize the learning issue in WSN and combine the ability of evolution of Genetic Algorithm and probability searching of Swarm Intelligence. In the future, we can develop more hybrid algorithms for optimizing the solutions of memory and computation power which alternatively affect other issues of wireless sensor networks and Table 5 can be a much help in it. More effective approaches of hybrid algorithms of CI paradigm can be used to solve the issues of WSN more efficiently. Few of

them are shown in Figure 4. Apart from the emergence of bio-inspired solutions in artificial systems in general as is intuited form Table 3, it has a lot contributions in the intelligent optimization of variety of applications in wireless communication domain specifically.

8. Conclusion

In this paper, we have elaborated the importance of bio-inspired algorithms for the optimal solutions of non-biological systems. We have figured out the key constituents of biological systems and their exploitation in developing the bio-inspired systems. It has been intuited from the Table 2 that the said solutions have their emergent importance in the intelligent optimization in a variety of applications in wireless

TABLE 4: Comparative analysis of various CI techniques.

Evaluation parameters	Artificial neural network (ANN)	Artificial immune system (AIS)	Fuzzy logic (FL)	Genetic algorithm (GA)	Swarm intelligence (SI)
<i>Development epoch</i>	1969	1986	1987	Late 1960's	Early 1990's
State variable	Mixed variable	Continuous and discrete variables	Discrete variable	Discrete variable	Continuous, discrete, and mixed variables
<i>No of search points</i>	<i>Multipoint search</i>	<i>Multipoint search</i>	<i>Multipoint search</i>	<i>Multipoint search</i>	<i>Multipoint search</i>
Solution guarantee	Rarely offers entire solution	Best for time varying solution	Appropriate	Definite in favorable ways	Precise
<i>Run time</i>	<i>Long</i>	<i>Medium</i>	<i>Short</i>	<i>Medium</i>	<i>Medium</i>
Target problem	- Combinatorial optimization - Multiobjective optimization	- Combinatorial optimization - Multiobjective optimization - Continuous optimization	- Combinatorial optimization - Multiobjective optimization	- Combinatorial optimization - Global optimization - Nonlinear optimization	- Combinatorial optimization - Continuous optimization - Nonlinear optimization
Features	- Adaptive learning - Self-organization - Fault tolerant	- Provides tools in local and global search - Powerful optimization tool - Self-adaptive and self-learning	- Improve system nonlinearity - Deterministic - Performs best even with small input - Accurate	- Solutions to optimization and search problems - Good global solutions	- Distributive approach - Self-organization - Decentralized control - Powerful optimization tool

TABLE 5: Hybrid bio-inspired-technique-based proposed solutions for various issues in wireless sensor ad hoc networks.

Hybrid Bio-inspired Technique	Proposed solution for various issues in wireless sensor ad hoc network
Neuroimmune	<i>Jabbari and Lang [63] have targeted the quality of service; network records are evaluated using an efficient data processing algorithm comprising of Neural Network and Artificial Immune System.</i>
Immune-swarm	Saleem et al. [64] have proposed nature inspired autonomous mechanism for network security without any central control.
Neurogenetic swarm	<i>Mishra and Patra [65] have proposed a hybrid technique that encompasses three bio-inspired techniques; Neural Network, Genetic Algorithm, and Particle Swarm Optimization to short-term forecasting of the load on nodes in sensor networks.</i>
Swarm fuzzy	Cui et al. [66] have presented a technique for node identification in the network without the help of global positioning system. This algorithm specifically targets the unsafe contaminant locations like border areas.
Genetic swarm	<i>Yanjing and Li [67] targets the design and deployment aspects of wireless sensor network. His proposed hybrid technique; Evolutionary and Particle Swarm Optimization Algorithms, ensures the maximum coverage of the underlying area by the sensor nodes.</i>
Neurofuzzy	The proposed cluster designing technique by Veena and Vijaya Kumar [68] is a merger of Neural Network and Fuzzy Logic bio-inspired techniques. The algorithm targets the routing of aggregated data in mobile wireless sensor nodes where the designed clusters are in dynamic form.
Genetic fuzzy	<i>Lui et al. [69] have given an idea for routing in wireless ad hoc networks. He proposed multipath routing technique that adopts its path according to the changing network topology in efficient way with respect to energy.</i>
Genetic neural	Gao and Tian [70] have targeted wireless sensor network security issue. He proposed that the data acquisition node uses sensors to collect information and processes them by image detection algorithm and then transmits information to control centre with wireless mesh network. The ability of strong self-learning and pattern classification and fast convergence of genetic-neural system resolves the defect and improves the intelligence.

communication domain. This paper has well elucidated the fact that real creation of the One has really the marvelous traits in it. These traits act as a guiding light for achieving the optimal solution of any artificial system. Biological systems ever provide the better solutions through its intelligent optimization techniques. If there arises any gap between

the bio-inspired solution and the artificial systems' problem then this gap can be bridged by carefully identifying the behavioral and architectural traits to develop the metaphoric relationship. The upshot of this paper leads to one step ahead to intradisciplinary research within the biological systems to come up with better bio-inspired solutions. This paper leads

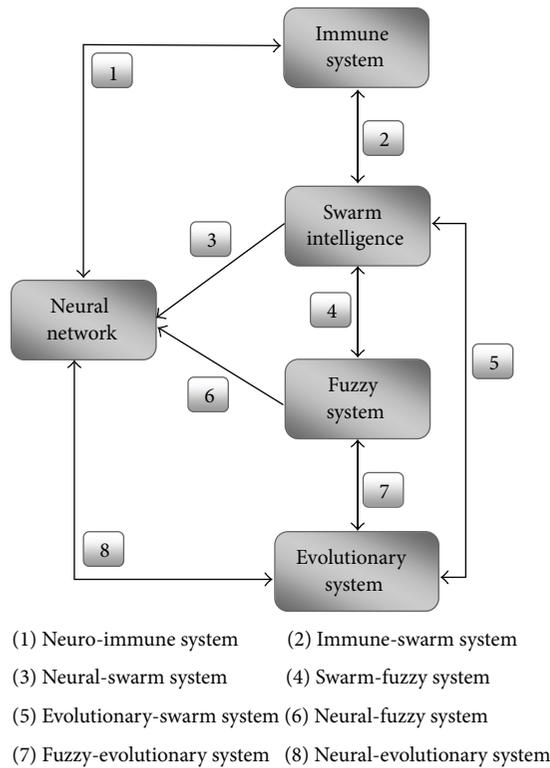


FIGURE 4: Hybrid bio-inspired techniques.

us to differentiate between various optimization problems existing in WSN collectively showing that hybrid and non-hybrid algorithms can efficiently optimize the problems in wireless sensor networks. The hybrid algorithms open new horizon in the optimization solutions of WSN.

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