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A Survey on Bio-inspired Routing Algorithms in Wireless Sensor Network

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Abstract

Wireless networks with their attractive features are finding popularity in many applications such as remote surveillance, military, civil, environment monitoring, etc. The wireless networks are usually deployed in hostile environments. It is difficult to change the batteries in such conditions so there is a need to conserve energy. In this work, a review of different types of bio-inspired algorithms is presented along with the detailed study of the artificial fish swarm optimization (AFSO) algorithm and its applications are discussed. The algorithm has four functions that are derived from the fish behaviors in fish swarms. This algorithm involves many characteristics such as high convergence speed, fault tolerance which help in solving the optimization problems. It is observed that the combination of AFSO with other clustering algorithms and different routing protocols provides greater accuracy in node formation and routing of the wireless networks. Furthermore, the comparative analysis is made by considering the AFSO protocols in different works with advantages and disadvantages.

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1 Introduction

Wireless sensor technology is growing expeditiously due to its expansion in the fields of data mining, distributed computing groups, and wireless networking (Selvakennedy et al., 2007). A large number of sensors in the network are deployed and the wireless networks with computational capability play an important part. The major applications of wireless sensor networks are target field, Weather monitoring, distributed computing, object movement, etc. There are different routing schemes present in wireless sensor networks. Due to the very limited battery capacity of nodes, routing in Wireless sensor networks becomes more challenging (Engmann *et al.*, 2018). Recently biologically inspired cooperative routing has brought much attention from many researchers (Iyengar *et al.*, 2007). Different types of characteristics such as robustness and scalability are present which helps the few globally complex structures to adapt to a new environment. The bio-inspired networking and communication protocols are devised by considering biology as a source of inspiration (Dressler and Akan, 2010). Bio-inspired is defined as the ideas which are influenced by or totally related to the biological structure of the organisms. This bio-inspired is an area of study which integrates the subfields of engineering, social behavior, and emergence. It also includes biology, computer science, and mathematics. Bio-inspired computing needs a group of algorithms that helps in the computation of the applications like pattern recognition and optimization processes. The development and the research of bio-inspired sensor systems have given many algorithms. These algorithms are discussed in detail and their application in different areas to solve the problems. There are different types of bio-inspired algorithms such as swarm intelligence and artificial immune system including the ant colony optimization and other bio-inspired routing protocols which helps in the optimization process of the wireless sensor networks. The features of the bio-inspired algorithms are described as follows, Robustness: The algorithms in this have strong robustness despite the changes in the environment. These algorithms have good applicability and flexibility.

Self-organization: These algorithms enhance adaptability by employing self-organization. *Emergence and simplicity*: The computations are very simple and the effects are very much amazing. The working method is the same as the biological mechanism of natural organisms. These types of algorithms/functions almost the same as the biological nature which helps in dealing with the real issues. This paper examines the biological-inspired algorithms and surveys the bio-inspired routing protocols applied to the wireless sensor network. The ASFO algorithm is employed with the aim of increased routing efficiency. The concepts of bio-inspired networking mainly depend on swarm intelligence and artificial immune system. The ASFO technique is the finest algorithms which are based on the swarm intelligence method. The algorithm is in view of the aggregate development of the fish and their distinctive social practices. Due to the different behaviors, the fish tries to retain their colonies and helps in demonstrating intelligent behaviors. This type of algorithm has many advantages such as flexibility, fault tolerance, high accuracy.

2 Biologically Inspired Routing Methods

The important difference between the engineered and the biological networks is that the engineered networks require alternative solutions to force the nodes to cooperate. The efficiency of the social insects to organize itself swear by basic four rules such as feedback of the systems which can either be positive or negative, irregularity, and frequent interactions. Biological systems as well as sensor networks present in the environment need to adjust themselves due to the changing environmental conditions such as scalability, Self-organize, and robust operation [6]. These algorithms represent a class of routing algorithms that is mainly focused on the computing of the applications such as optimization processes, pattern recognition, etc. There are different routing protocols in bio-inspired networking and communication, one such area is swarm intelligence. Biologically inspired algorithms are organized and explored based on their applications in different fields, their mathematical model, its advantages over the classical approach, its biological source, limitations and border conditions, and its potential for future applications [7]. Bio-inspired methods can be mainly divided into swarm intelligence methods and evolutionary algorithms. Figure 1 classifies bio-inspired algorithms.

2.1 Swarm Intelligence Methods

Swarm intelligence methods are originated from biological phenomena and the research efforts have been focused on analyzing and thus developing the algorithms that are inspired by biological phenomena and thereby deploying these algorithms in computer networking applications. These swarm intelligence methods study the group of agents that enable intelligent behavior in complex environments and it is a collective intelligence of social insects and birds to solve distributed problems. The complete task of an individual in many areas of engineering is necessary. There are many dense groups of small insects like ants that address similar problems. The overall productivity of ants in a group is more than the sum of individual activities. The rules are simple and are followed to lead an impressive global behavior. The algorithms and protocols which are studied in the domain of swarm intelligence are applied in many areas. There are different methods of Swarm intelligence few of them are described below,

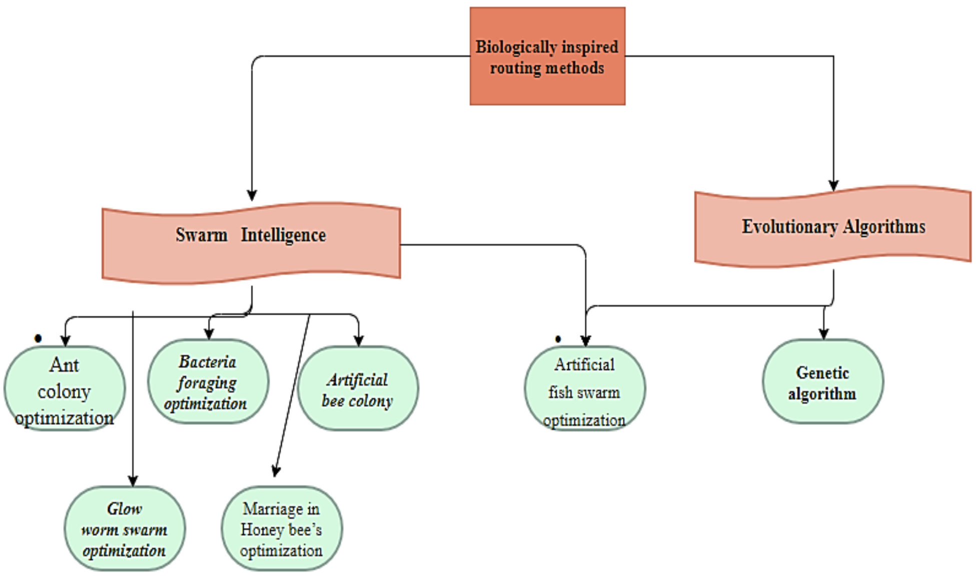

Figure 1: Classification of Bio-inspired Algorithms.

2.1.1 Ant Colony Optimization

This optimization technique is triumphant among other swarm algorithms which were presented by [8]. This algorithm was inspired by exploring the nature of ants (foraging). There is indirect communication amongst an organizing emergent system. The ants can compute the briefest way between the home and the nourishment sources by examining the path[9]. In this manner, ants pick a way to pursue a choice. Later the routes are created by a high concentration of pheromone. The algorithms can be designed By modeling and simulating the nest building which is used for complex and optimization problems. The ant colony optimization is designed into three main functions such as,

- Pheromone update
- Ant solutions construct
- Daemon actions

Further, so as to upgrade the presentation of the subterranean ant system, the ant colony system was introduced. The performance depends on different modifications employed in the system. The modifications involve following a different rule for transition, different rules for trail updating, the usage of the list of the candidate in restricting the choice, and the use of local updates of the pheromone trail [10].

The major disadvantage of this system is that it is not able to overcome the link failures and improve the quality of the metrics. The main advantage is that the network performance is enhanced by increasing network lifetime, by proper load balancing of the network by optimizing solutions.

2.1.2 Bacteria Foraging Optimization (BFO) Model

This data routing algorithm model is also inspired by the biological phenomenon of the foraging nature of Escherichia coli bacteria. In this model, the operational work is partitioned into three different phases. Chemo taxis is the initial stage where the efficiency of the nodes in WSNs is measured by the closeness of the nodes with other neighbor wireless sensor nodes. The second stage is a reproduction, wherein the wireless sensor nodes which are more efficient than other sensor nodes are selected and they are employed as cluster heads that monitor and employ the neighboring nodes under its cluster. The third and last phase is concluded when the efficiency of the nodes which were employed as cluster head is reduced and is lesser when compared to neighboring nodes present in the cluster are eliminated and after elimination, all the nodes present in the cluster are released (Mishra et al., 2015). The results of this algorithm are better than the traditional algorithms (Swarm intelligence-based) with respect to computational efficiency. This algorithm is image quantization and faces recognition along with data routing.

2.1.3 Artificial Bee Colony-based Protocols

This model of the data routing algorithm is also bio-inspired and has the nature of the bees (unlike ants) in a group or swarm. This algorithm optimizes the continuous and multivariable functions. The bee swarm is made up of three different types of agents such as scout bees, onlooker bee, and employed bee. The agents mentioned above have pre-defined functions that perform with different operational phases in a network.

I. Initialization phase: It starts with the initial number generated randomly through a group of vectors.

II. Employed bee phase: After initialization, the efficiency of the agents is measured based on the result which is observed in the previous phase.

III. Onlooker bee phase: In this phase, the efficiency of the agents are measured and highly efficient agents are selected and they are employed as cluster heads. These agents serve as data-centric nodes for collecting data from other nodes.

IV. Scout bees phase: In this phase, random searching is performed to discover different sources for food. If the solution is not found then the food source is neglected and left inconsiderate and the bee responsible for this is transformed into a scout bee.

This model has several disadvantages. The rate of convergence is less and the process flow is not efficient and it also results in the overhead which reduces the throughput.

2.1.4 Glowworm Swarm Optimization

This is another type of swarm intelligence methodology which aims at the optimization of the modal functions. They employ physical entities called glow-worms. These glow-worms are spread randomly in workspaces and are not placed in the finite regions. The three phases performed in the ant colony optimization is executed and they are called luciferin level update, glow-worm movement update (Krishnanand and Ghose, 2009). The efficiency of the present position of the glow worm m is calculated as

$$lm(y) = (1 - n).lm(y - 1) + J\,(xm(y)) \quad (1),$$

where n = luciferin evaporation factor and constant J = objective function (Zhang *et al.*, 2011).

2.2 Evolutionary Algorithms

This is another type of bio-inspired algorithm which has a genetic routing protocol as the classification algorithm. The term evolutionary algorithms are used to refer to several search and optimization algorithms that are inspired by the process of natural evolution. These algorithms refer to numerous search optimization techniques that are based on natural evolution (Fonseca and Fleming, 1998). This is another type of bio-inspired algorithm which has a genetic routing protocol as the classification algorithm.

2.2.1 Genetic Algorithm

The genetic algorithm is an evolutionary algorithm that is proposed in the past. This algorithm carries the process of natural evolution. This is a kind of optimization approach which is based on individuals that generate another population during an iteration. These are the particular class of the evolutionary algorithms which depends on the techniques which are taken from the evolutionary biology such as inheritance and mutation etc. (Ranganathan *et al.*, 2006) made the first attempt to take a systematic approach using the genetic algorithms which always focused on the problem of the heterogeneous networks to optimize the global function properties through the adaptive rules. Thus, the approach says that it can be used in other self-organizing systems.

3 Artificial Fish swarm optimization

Artificial fish swarm optimization is one of the swarm intelligence methods and also evolutionary optimization techniques (Neshat et al., 2017)This is demonstrated from social collaborations of the fish bunches in nature. This technique consists of different functions that are derived from the behavior of the fish in the fish swarms. Considering, initially the fish travels without any restriction in the group when they are not sensing their prey. The next factor to be considered is the behavior of the prey. This algorithm has an area that allows an artificial fish to identify its prey and this is designed as a neighborhood. The third function is the following behavior. The artificial consists of two parts such as variables and functions. The variables include Y= (y_1, y_2, y_3, $y_{4.}$ y_n) and are considered as the present state of the artificial fish. The step has the functions which have the behaviors called swarming, preying, and the following is explained as follows.

Swarming behavior: To protect themselves the fish, congregate naturally and considering x1 as the artificial present state, Ycc is the cental state and n is the number of the other nodes in its neighborhood and n is the total number of fish.

Preying behavior: In this stage, the fish is allowed to move in water randomly and when they identify their prey, they move in the direction of the prey. Following behavior: When fish senses their prey, other fish follow their respective partners to reach their prey.

3.1 Cluster Formation Using AFSO

The Existing cluster formation algorithm such as LEACH distributed algorithm does not give any assurance about the arrangement and count of cluster head nodes (Neshat *et al.*, 2012). As the clusters are adaptive in nature the performance is not affected and the operating process of the AFSO follows the central control algorithm which helps in producing the good clusters by distributing the cluster head nodes randomly in the network arena. The designed phase of the AFSO sensor node clusters has a node that provides data with the current state and the amount of energy it gains to the base stations. The nodes having the energy average or below cannot become cluster heads (Song *et al.*, 2010). The execution process is explained in the below steps.

Step 1: Initialization of artificial fish swarm, X = (x_1, x_2,......x_n) which includes all the cluster heads and other factors like visual (sensory distance), the crowd factor number of cycles, etc.

Step 2: After step 1, the present state function value Z of every artificial fish is calculated. The calculated value is allotted to the most efficient fish. The object function of each artificial fish is determined from

$$Z = f(x) = minj = 1nxsjX - mj \qquad (2),$$

where mj is the mean of the vector j.

Step 3: The behavior of fish following and swarming are simulated and the results are selected in object function value Y. The most followed behavior is the behavior of the fish when it senses its prey and moves towards that direction.

Step 4: The new central point is examined using the function in Equation (1) and the artificial fish swarm similarity is calculated using the formula

$$F\ (xi)\ =\ 1/2(\frac{1}{kj})\ =\ 1, j1k\ mci\ -\ mcj\ +\ 1/Y\ ) \quad (3),$$

k = number of clusters, mci, mcj is the center position in the process of the cluster.

Step 5: Check if the maximum iteration number has been achieved and if it is not achieved then we have to follow step 2 and if the maximum iteration is achieved then we can move towards step 6.

Step 6: Output the optimum solution

3.2 Improved Basic behaviors in AFSO

The performance of the AFSO is enhanced through different behavior (Neshat *et al.*, 2012). Figure 2 shows the classification of fish behaviors.

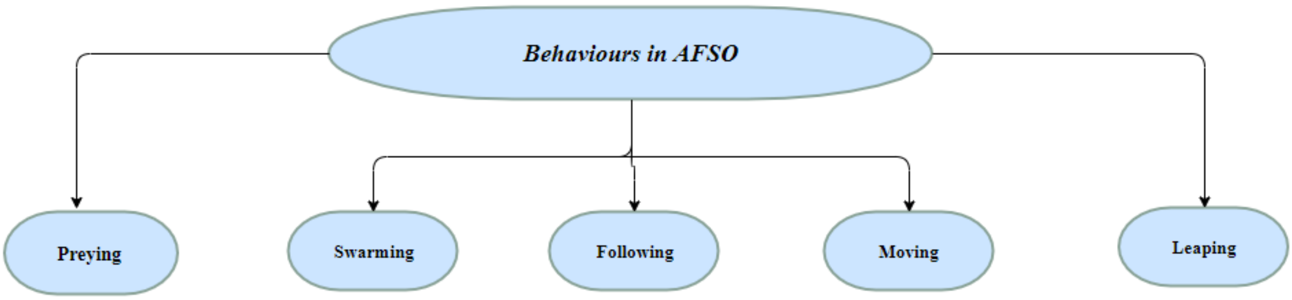

Figure 2: Classification of Behaviors in AFSO.

3.2.1 Preying Behavior

This is one of the biological behavior that attracts to foods and usually, the fish concentrates on the prey to evaluate the movement of the prey by sensing it. Here, Yi be the present state of artificial fish, Yj is the distance, Z is represented as the food concentration factor. It is observed that if the visual distance is more, then the fish tries to identify the global value for converging.

$$Yj\ =\ Yi\ +\ visual.rand() \quad (4).$$

If Zi ≠Zj then a step forward is reached.

$$Y\ (t+1)i\ =\ Yi(t)\ +\ YJ\ -\ Yi(t)|Yj\ -\ Yi(t)|.step.rand() \quad (5).$$

Yj is a selected state and it is checked whether it can satisfy the forward condition.

3.2.2 Swarming Behavior

To avoid dangers the fish always move in groups and the process of moving in groups is proof of the existence of the colony. Here, Yi is the present state of the artificial fish, Xcis the center state, and nf will be the number of companions in the neighbourhood and n will be the overall fish count. If Zc>Zi and nf/ni then the neighbouring center will have more food. If Zc<Zi, then the swarm is less crowded and it switches to the next center.

$$Y(t+1)i = Yi(t) + Yc - Yi(t)|Yc - Yi(t)|.step.rand() \quad (6).$$

3.2.3 Following Behavior

The process continues and the behavior in the moving process is evaluated. When a fish (Either a single or group of fishes) identifies its prey and all the fish in the neighborhood rushes towards it. Here, Yi is the present state of fish and j is a swarm neighborhood and it has a high value of Zj. If Zj>Zi and nf≠ni it proves that Yj has greater food concentration.

$$Y(t+1)i = Yi(t) + Yj - Yi(t)|Yj - Yi(t)|.step.rand() \quad (7).$$

3.2.4 Moving Behavior

Fish swims randomly in water and searches for food and companions in greater ranges. Choose a state randomly and it moves towards the particular state and as it is a behavior of prey and it is defined as

$$Y(t+1)i = Yi(t) + visual.Rand() \quad (8).$$

3.2.5 Leaping Behavior

The artificial fish behaviors result will be almost the same and the food concentration and values reduce within a few iterations. If the objective function is almost the same as the given percentage during the (m-n) iterations then the fish selects random fish present in the swarm and the conditions are random to select the artificial fish.

If $(BestFC(m) - BestFC\ (n)) < eps,$

$$Y(t+1)some = Ysome(t) + visual.Rand() \quad (9).$$

Thus, the artificial fish swarm results in a moving process of few fishes present in the swarm to move towards a fish tending in the global extreme value.

3.3 Applications of AFSO

This algorithm is used for optimization purposes and different applications are described.

3.3.1 Control Technique

i. Artificial fish swarm algorithm for fuzzy logic controller

The controlling methodology shows the overall review of the AFSA used in the design process and in the optimization of the fuzzy logic controller. The process which has input and output variable function characterized by the different parameters thereby giving the advanced performance enhancement of the fuzzy logic controller which employs the AFSA technique. This has the advantage to improve the capability of search. The results obtained using this method show that the controller employing AFSA proves its feasibility (Tian *et al.*, 2009).

ii. AFSA for multi-robot task scheduling

This significant task is managing the robots and their responsibilities to decrease the deviation between the asset necessities and alluring levels. The different types of source leveling methods are proposed to resolve the task sharing difficulties in multi robots. The experiments which are conducted on the robots show that the proposed methods have greater performances. It also has the advantages of strong robustness, fast global convergence, etc. (Tian and Liu, 2009).

3.3.2 Image Processing

i Artificial fish fuzzy C means clustering algorithm

In this technique, the partitioning of an image into multiple images is done using the above-mentioned algorithm. along with this, an AFSO technique is also discussed in this segment. The AFS algorithm is associated with FCCA and by studying the behavior of prey and by following the swarming nature of artificial fish the optimizing center for clustering methodology can be selected. Results show that the proposed algorithm is advantageous and effective (Chu *et al.*, 2010).

ii. WSN-AFSA

Robust communication protocols are required for the proper functioning of wireless sensor networks and also for proper load balance. The method has been proposed with the different routing protocols employing AFSO. It utilizes the AFSO algorithm in the cluster formation phase and the solution for the k optimal clusters adhering to the set of conditions. This proposed protocol is compared against LEACH protocol which is a cluster-based protocol. The results show that the protocol helps in improving the system lifetime and reduces energy utilization. (Song *et al.*, 2010).

iii. AFSA in Intrusion Detection

The optimization technique and simplifying the network features employing the AFS algorithm in the detection of the intrusion is discussed. The optimization technique and simplifying the network features employing the AFS algorithm in the detection of the intrusion is discussed. When the rate of detection is high, then the false positive rate will low. This is derived by employing optimization techniques based on different behaviours which include hunting, swarming, and follow operators. The highlights are altered and are made simpler by using this technique. The end results show that by using this method the features can be optimized.

3.3.3 Neural Networks

i. Forecasting Stock Indices using RBFNN by AFSA

The financial arena is trending in stock market forecasting. The stock indices are always challenging for the researchers. The RBFNN is used to extract the figurative information and transfer it to the Shanghai stock exchange. So the AFSO is used to optimize the radial basis function (Shen, 2011). Also, to enhance the efficiency of the forecasting process, the K means clustering algorithm is elaborated by the fish swarm technique for radial basis function. The results of the experiment show that RBF that is optimized by AFSA is a better kind of algorithm with better efficiency.

3.3.4 Scheduling

i. Efficient Job Scheduling in Grid Computing with Modified Artificial Fish Swarm Algorithm

The main criteria that need to be addressed in grid computing are improving the quality of job scheduling. The improved version of the AFS algorithm is implemented for job scheduling and the reason behind implementing this is to adopt the behavior of fish along with the search of individual fish for demonstrating global optimism. Results prove the employed technique is non-effective to initial values and has solid strength and better estimation precision (Farzi, 2009).

4 Comparative analysis

This session consists of the analysis of previous works on AFSO algorithms. Table 1 summarizes the contributions of various papers with the technique used, the outcomes of the paper, and the research gap. Table 2 reviews various artificial fish swarm optimization algorithms used for clustering and routing in wireless sensor networks. It describes the methodology used, the objective of the work, the results, the previous works used for comparison, and the performance metrics used for comparison.

Table 1: Summary of AFSO algorithm in a wireless sensor network.

Author	Technique Used	Outcome	Research Gap
Li (2010)	Dynamic fuzzy C clustering with AFSO	Raise of the clustering efficiency	Difficult to obtain globally optimal solutions
Liu *et al.* (2009)	QOS multicast routing based on AFSO	High reliability and good performance	Space complexity
Yang and Yong (2006)	By activating the sleeping nodes with swarm intelligence	Improves the network coverage	Deployment for the practical applications is a little difficult
Dong et al. (2012)	Network coverage improvement algorithm employing AFS algorithm	The network coverage rate is higher when compared with the Particle swarm optimization	The 3D coverage rates rely upon the monitoring of the multimedia WSN
He et al. (2009)	Artificial fish swarm algorithm with adaptive visual and adaptive step in fuzzy clustering	This experiment result shows that the proposed method overcomes the optimal problem of the fuzzy C means clustering	These algorithms need to be integrated with other clustering approaches
Gui *et al.* (2016)	Spider monkey optimization algorithm	This algorithm outperforms the other data-driven routing protocols	This considers few parameters when comparing with other data-driven routing protocols and does not consider artificial systems

Table 2: Comparisons of AFSO Routing Algorithms

Author	Methodology	Objective	Result Outcome	Previous Works Compared	Future Work	Performance Metrics
Song et al. (2010)	The hierarchical routing protocol based on AFSO	Balancing the load and prolonging the network lifetime.	Prolongs the entire network lifetime, improves energy efficiency.	LEACH, LEACH-C	Propose some biological-inspired algorithms to solve routing, flow control, congestion control, security issues in WSN	A number of alive nodes, energy dissipation.
Azizi et al. (2015).	Artificial Fish Swarm Algorithm (AFSA) for clustering procedure	Improve clustering of nodes	Improved clustering	LEACH,G-PSO,CM-AFSO,Std-ICA	Improve clustering in mobile sensor network	The remaining energy in the network, SD of First node died(FND), the Last node died(LND)
Helmy et al. (2015)	Artificial Fish Swarm Algorithm for clustering	To prolong the network lifetime	the better life span for individual nodes as well as for network systems	PSO, LEACH	Taking into account the communication cost, its effect on network lifespan	A number of alive nodes for different clusters, residual energy of nodes in each cluster.
Rushdy et al. (2018)	Modified AFSA	Energy holes and coverage problems, Enhancing the network lifetime	Decreased energy consumption and improved network lifetime	OHRT, LEACH, PSO	Adjustment of the proposed convention to be applied in practical scenarios Heterogeneous and mobile network	A number of active Nodes, maximum value and mean value.

5 Conclusion

In this research, a review is conducted on different routing algorithms that are inspired by biological phenomena in WSN. The different types of algorithms used in biologically inspired routing methods such as swarm intelligence methods, evolutionary algorithms, optimizing ant colonies, bacteria foraging optimization model, artificial bee colony-based protocols, etc. are reviewed. Artificial swarm optimization is one of the swarm intelligence methods which is studied in detail. The different behaviors of the AFSO algorithm are explained. The algorithm depicts advanced behavior and elaborated results when contrasted with different SI algorithms. The applications of the artificial fish swarm optimization algorithm in various fields are studied. The analysis of the existing AFSO algorithm is performed. Thus the bio-inspired algorithms have many advantages such as better field coverage, global search ability, great convergence speed, potential in sensor deployment and the future work needs to focus more on the deployment and more practical applications.

6 Availability of Data And Material

Data can be made available by contacting the corresponding author.

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