A Comprehensive Survey on Nature Inspired Heuristic Algorithms for Energy Efficiency in Wireless Sensor Network

[1]Mr. P. Ravikumar, [2]Dr.P. Ganesh Kumar,

[1]Associate Professor, [2]Professor,
[1.] Department of Electronics and Instrumentation
[2.] Department of Information Technology
[1,2]K.L.N. College of Engineering, Tamilnadu, India

Abstract **- Today's Engineering Study is highly motivated towards the Nature Inspired heuristic computational algorithm as they have the competence to give better results as compared to the conventional methods. Wireless Sensor Networks (WSNs) have become gradually prevalent due to their wide array of applications. Developing an energy-efficient routing algorithm is an important issue in the conspiratorial of WSNs applications as the lifetime of the sensor node is based on limited battery-powered devices. Therefore, to maximize the lifetime of the sensor node an extensive survey of energy-efficient routing algorithms based on natural science has been addressed in this paper. The paper will take the readers into a detailed survey of existing energy-optimized routing algorithms considering the natural science (heuristic) as the base and considering parameters related to energy efficiency as the core objective.**

Keywords: **Nature Inspired Computing, WSN, Energy Optimization, Optimized Routing**

1. INTRODUCTION

WSNs are defined as a network of tiny implanted devices, called sensors, which communicate wirelessly among themselves. WSNs are located deliberately in a physical medium and can interact with it to measure physical parameters from the environment and provide sensed information [1]. The nodes mainly use a transmit communication tactic and the network topology, which can change constantly since nodes are prone to fail. The nodes have limited power, low computational capabilities, and limited memory. One of the main issues that should be studied in WSNs is their scalability feature [2], connection stratagem for communication [3], and the limited energy available to supply the device. The craving for advances in research and development of WSN was initially aggravated by military applications such as surveillance of threats on the battlefield, mainly because WSN can replace single high-cost sensor assets with large arrays of distributed sensors. There are other interesting fields like home control, building automation, and medical applications. WSNs can also be found in environmental monitoring applications such as marine fish farms [4] and fire detection units in forest and rural areas [5]. Ant and honey bee communities have all-around communal deeds along with a decentralized organization structure as stated by the authors [6] [7]. This synchronization of activities among social insects helps them solve genuine world problems in the simplest ways. This uniqueness shown in the social insects can be mapped in the context of WSNs where nodes work together to achieve a regular objective in the deployed environment. The most important purpose of this survey is to present a comprehensive review of different power-saving and energy-optimization techniques available for WSNs taking into contemplation the nature-inspired heuristic techniques. We will discuss all major modern meta-heuristics algorithms as genetic algorithms, ant colony optimization, and cuckoo search. The below table shows the nature-inspired meta-heuristics species in terms of behavior and how it is applied in WSN.

Table.1. Natured inspired species

Nature Species	Behavior	Applied Applications in WSN

Swarms	Swarm behavior is a collective behavior exhibited by animals of similar size, which aggregate together or migrate in some direction. Swarms represent an individual animal that follows three rules: 1) They move in the same direction as their neighbors move. 2) Always remain close to their neighbors. 3) Keep away from collisions with their neighbors	The distributed system of interacting, autonomous agents, performance enhancement, process optimization, distributed task allocation
Honey Bees	Proficiently combine replication and evasion to allow the network to continue to deliver data for a long time during a congestion attack.	An energy-aware defense framework against base-station congestion attack in WSNs
Ants	Control is fully distributed among several individual communications among the individuals happening in a localized way. The overall response of the system is quite robust and adaptive concerning changes in the environment.	Allocation of the computing; resources to the number of cluster units; control can be fully distributed among several clusters; cluster interacts in simple and localized ways
Wasps	A colony of individuals working together for the survival of the colony. Coordinate their behavior to build such a complex nest structure.	Applications of self-assembling robots; cluster formation in sensors and evolutionary design to architecture in WSN
Termites	Termites move from a non-coordinated to a coordinated phase only if their density is higher than the threshold value.	To balance the network traffic load and prolong the network lifetime without performance degradation
Fish Schools	Any group of fish that have collectively come together in some locality is termed an aggregation of fish. These can be structured or unstructured. An unstructured aggregation is a group of mixed species and sizes that gathers at random near some neighboring resource, such as food or nesting sites.	Used for node deployment algorithms, and node clustering with many applications, for example, Traffic Monitoring Systems.
Cuckoo's	It was motivated by the behavior of cuckoo species and their method of laying eggs in the nests of other host birds. This is the basic motivation for the development of this new evolutionary optimization algorithm.	Solving optimization problems in WSN and for searching performance improvement; efficiency plotting of nodes in graphs and trees.
Chameleon	It was inspired by the behavior of chameleon species where the chameleon changes its color dynamically according to the environment.	Dynamic modeling to determine the similarity between pairs of clusters

Bat	Inspired by Bat Algorithm, a novel algorithm, which is called Evolved Bat Algorithm (EBA), for solving the numerical optimization problem is proposed based on the framework of the original bat algorithm.	Applied for Energy Efficient mechanism, Deployment of nodes in WSN, and Localization in a wireless sensor network for various frameworks.
Dragon Fly	The main inspiration of the DA algorithm originates from the static and dynamic swarming behaviors of dragonflies in nature. Two essential phases of optimization, exploration , and exploitation, are designed by modeling the social interaction of dragonflies in navigating, searching for foods, and avoiding enemies when swarming dynamically or statistically.	Using it improves the optimal use of Energy consumption in Industrial wireless sensor networks.
Elephant herding	The EHO method is inspired by the herding behavior of the elephant group. In nature, the elephants belonging to different clans live together under the leadership of a matriarch, and the male elephants will leave their family group when they grow up. These two behaviors can be modeled into two following operators: clan updating operator and separating operator. In EHO, the elephants in each clan are updated by their current position and matriarch through the clan updating operator. It is followed by the implementation of the separating operator which can enhance the population diversity at the later search phase.	Addressing the Network Localization problem and Energy Efficient Cluster head selection.
Gray wolf	The GWO algorithm mimics the leadership hierarchy and hunting mechanism of grey wolves in nature. Four types of grey wolves such as alpha, beta, delta, and omega are employed for simulating the leadership hierarchy.	Grey wolf algorithm was employed in forming the clusters and the cluster head selection process towards the improvement of network lifetime.
Whale	Whale Optimization Algorithm (WOA), which mimics the social behavior of humpback whales. The algorithm is inspired by the bubble-net hunting strategy.	Solving Network coverage issues also addresses the cluster head selection problem while extending the Network life span.

2. INTELLIGENT SOLUTIONS USING NATURE-INSPIRED SYSTEMS

There are various energy optimization techniques based on nature-inspired systems. Numerous problems exist in our day-to-day life, which are difficult to solve in conservative ways because of their limitations. Therefore, many researchers have shifted their focus from traditional ways of nature-inspired ways to solve these problems. Nature-inspired algorithms have their methods and principles to resolve problems. For this one should understand nature's principles, rules, and mechanisms of working. The process of designing intelligent systems through nature inspiration has the following phase: understanding the natural process, designing patterns of the natural process, identification of analogies, and technological modeling for the problem [8]. One of the key features of nature-inspired systems is searching for the best solutions in the optimization space. Most of the time, the optimization process needs iterations of working sessions. Foraging behavior in ants and bees systems, bird flocking, herds, wasps, fish schools, genetic systems, Cuckoo, Chameleon, termites, Bat, Elephant, Wolf, and Dragon fly's functions, are some of the typical examples of iterations of working sessions for the optimal respective solutions for WSNs

3. REVIEWS OF NATURE-INSPIRED METAHEURISTICS ALGORITHMS

The focus of our review is to provide extensive exposure to the offered literature. We have discussed the revolutionary efforts, the most influential work, and the recent trends in the area for each of the topics. We have referred to the following species during the whole review work: the ant, the cuckoo Bat, Wolf, Whale, and the genetic-based clustering and routing protocols inspired by nature.

3.1.THE ANT COLONY OPTIMIZATION (ACO) APPROACH

Ants are social insects that live together in organized colonies whose population size can range from about 2 million to 25 million. When foraging, a swarm of ants or mobile agents interact or communicate in their local environment. Each ant can lay scent chemicals or pheromones to communicate with others, and each ant is also able to follow the route marked with pheromones laid by other ants. When ants find a food source, they mark it with pheromone as well as mark the trails to and from it. From the initial random foraging route, the pheromone concentration varies. The ants follow the routes with higher pheromone concentrations, and the pheromone is enhanced by the increasing number of ants. As more and more ants follow the same route, it becomes the favored path. Thus, some favorite routes emerge, often the shortest or more efficient. This is a positive feedback mechanism.

Emerging behavior exists in an ant colony; such emergence arises from simple interactions among individual ants. Individual ants act according to simple and local information (such as pheromone concentration) to carry out their activities. Although no master ant is overseeing the entire colony and broadcasting instructions to the individual ants, organized behavior still emerges automatically. Therefore, such emergent behavior can be similar to other self-organized phenomena that occur in many processes in nature, such as the pattern formation in some animal skins (e.g., tiger and zebra skins).

The foraging pattern of some ant species (such as army ants) can show extraordinary regularity. Army ants search for food along some regular routes with an angle of about 123◦ apart. We do not know how they manage to follow such regularity, but studies show that they could move into an area and build a bivouac and start foraging. On the first day, they forage in a random direction, say, the north, and travel a few hundred meters, then branch to cover a large area. The next day they will choose a different direction, which is about 123◦ from the direction on the previous day, and so cover another large area. On the following day, they again choose a different direction about 123◦ from the second day's direction. In this way, they cover the whole area over about two weeks and then move out to a different location to build a bivouac and forage in the new region.

The interesting thing is that ants do not use the angle of 360◦ ⁄3 = 120◦ (this would mean that on the fourth day, they will search the empty area already foraged on the first day). The beauty of this 123◦ angle is that after about three days, it leaves an angle of about 10◦ from the direction of the first day. This means the ants cover the whole circular region in 14 days without repeating or covering a previously foraged area. This is an amazing phenomenon.

ACO was pioneered by Marco Dorigo in 1992 [9, 10] and is based on the foraging behavior of social ants. Many insects such as ants use pheromones as a chemical messenger. Ants are social insects and live together in organized colonies consisting of approximately 2 to 25 million individuals. Each ant lays scent chemicals or pheromones to communicate with others. Each ant is also able to follow the route marked with pheromones laid by other ants. When an ant finds a food source, it will mark it with a pheromone and also mark the trail to and from it.
However, the pheromone concentration ϕ decays or evaporates at a constant rate γ. That is,

$$\phi(t)=\phi_0 \exp[-\gamma t]$$

where, ϕ_0 is the initial concentration at $t = 0$. Here evaporation is important, as it ensures the possibility of convergence and self-organization.

From the initial random foraging route, the pheromone concentration varies and the ants follow the route with a higher pheromone concentration. In turn, the pheromone is enhanced by the increasing number of ants. As more and more ants follow the same route, it becomes the favored path. Thus, some favorite routes emerge, often the shortest or more efficient ones. This is a positive feedback mechanism. As the system evolves, it converges to a self-organized state, which is the essence of any ant algorithm.

3.1.1Ant colony optimization-based routing in WSNs, 2013:

In this publication [17] the author K. Syed Ali Fathima et al. have presented a new protocol for WSN routing operations. The protocol is achieved by using the ACO algorithm to optimize routing paths, providing an effective multi-path data transmission to obtain reliable communications in the case of node faults. The authors aimed to maintain network lifetime at maximum, while data transmission is achieved efficiently. The author's study was concluded to evaluate the performance of the ant-based algorithm and AODV routing protocol in terms of Packet Delivery Ratio, Average end-to-end delay, and Normalized Routing Load. From the comparison, it is concluded that the overall performance of the ant-based algorithm is better than AODV in terms of throughput. The proposed algorithm can control the overhead generated by ants while achieving faster end-to-end delay and improved packet delivery ratio.

3.1.2Prolonging the lifetime of WSN based on a blending of genetic algorithm and ACO, 2015:

In this paper [18] the author Soumitra Das et al. have proposed an algorithm, which is a combination of two techniques i.e. Genetic Algorithm (GA) and ACO to prolong the network lifetime and save the energy of sensor nodes, which is the need of the sensor network. Here, the GA is used for the formation of the clusters and selection of the Cluster Head (CH). Once the cluster is formed and CH is chosen, the ACO algorithm is applied to find the shortest path from source CH to the destination sink using a multipath routing algorithm. The multipath routing helps in reliable communication when the node fails in between the route. The proposed algorithm was simulated in MATLAB R2009b and was compared with Genetic Algorithm Based Energy Efficient Clusters [GABEEC] and EEABR. The evaluation of the algorithm was done by comparing the following parameters energy consumption concerning time, energy comparison in each round, network lifetime, and throughput of the network, which indicates that the proposed algorithm conserves more energy.

3.1.3 Energy Optimization of ant colony algorithm in wireless sensor network, 2017

In this paper [19] the author Peng Li et al. proposed an algorithm that allows each node in a wireless sensor network to save the distance and residual energy of neighbor nodes. Furthermore, in terms of probability selection of the nodes and the pheromone update, this algorithm focuses on the next hop node through the comparison of the distance between the nodes and the residual energy, which ensures less possibility of nodes with low energy selected as the next hop. Therefore, the proposed algorithm improves energy load balancing, and stability of the wireless sensor network and, eventually, extends the life span of the wireless sensor network. The simulation results show that the improved ant colony algorithm avoids too much energy consumption of a certain local node resulting in more uniform energy consumption for each node.

3.2. THE CUCKOO SEARCH APPROACH

Cuckoo searching (CS) is an optimization algorithm developed by Xin-she Yang in 2009 [29]. It was inspired by the necessitated offspring parasitism of some cuckoo species by laying eggs in the nests of other host birds of other species. Some host birds can engage in direct conflict with the interfering cuckoos. For example, if a host bird discovers the eggs are not its own, it will either throw these alien eggs away or simply abandon its nest and build a new nest elsewhere. Some cuckoo species such as the new worlds brood-parasitic CS search idealized such breeding behavior and thus can be applied to various optimization problems. It seems that it can outperform other heuristic algorithms in applications.

Representations of CS:

- Each egg in a nest represents a solution, and a cuckoo egg represents a new solution
- The aim is to use new and potentially better solutions (cuckoos) to replace a not-so-good solution in the nests. In the simplest form, each nest has one egg
- The algorithm can be extended to more complicated cases in which each nest has multiple eggs representing a set of solutions

Three idealized rules of CS:

I. Each cuckoo lays one egg at a time, and dumps its egg in a randomly chosen nest;
II. The best nests with high-quality eggs will carry over to the next generation;
III. The number of available host's nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with a probability *Pa* € (0,1). Discovering operates on some set of worst nests, and discovered solutions dumped from further calculations.

3.2.1 Energy Efficient Cluster Formation in WSNs using Cuckoo Search, 2011:

In this paper [31] the author Manian Dhivya et. al. has focused on the issues related to the reduction of energy utilization and persistence of the lifetime of the network. The authors have proposed a meta-heuristic optimization technique called CS to aggregate the data in the network. The authors have divided the nodes into two categories as least energy nodes, responsible for sensing the data, and high energy nodes, for acting as CHs for communication with the base stations. The *CH* is selected from the best fit of the CS process. The objective was to fairly balance the energy consumption among the sensor nodes, according to their residual energy, and to extend the permanence of the network. The proposed algorithm was simulated in MATLAB (7.11.0.584) and compared with HEED and LEACH considering the network lifetime and energy consumption as the parameters. From the results, it is clear that the proposed method prolongs the network lifetime by 15% more as compared to HEED and LEACH.

3.2.2 Clustering approach for WSNs based on CS Strategy, 2014:

In this paper [35] the author Sandeep Kumar E et.al has concerted on the clustering in the WSN concept to save the energy of the sensor nodes in the network. They have proposed brood parasitism of a few cuckoo bird species, thereby increasing the lifetime of the network. This was an attempt towards bio-inspired computing in WSNs for achieving energy efficiency. The simulation was carried out in MATLAB 2013 by considering the following parameters as 100 numbers nodes plotted in the 100m × 100m area. The authors compared their proposed algorithm with basic LEACH concerning residual energy against rounds; the number of dead nodes against rounds and the comparison of network residual energy for different values of rejection probability threshold and the comparison of the number of dead nodes for different values of rejection probability threshold. The results clearly showed that the proposed algorithm is outstanding in terms of energy efficiency and it prolongs the network lifetime as compared to basic LEACH.

3.2.3 Improved Cuckoo Search-based Clustering Protocol for Wireless Sensor Networks, 2018:

In this paper [36] the author Gupta has proposed the improved cuckoo search-based clustering protocol for WSNs towards the extend the lifetime Network. In the survey, the clustering-based technique for data collection has proved very efficient in terms of energy saving. Although the design of energy-balanced clustering for improving the lives of the network is an NP-hard problem. For solving this problem, many heuristic approaches are proposed in recent years. However, the existing clustering-based deal has suffered from unbalanced energy consumption issues. To rectify this issue, the Improved Cuckoo Search-based Clustering Algorithm (ICSCA) is proposed in this research paper. Performance evaluation of ICSCA and its comparison with the state-of-art clustering scheme in terms of total energy consumption and residual energy is presented.

3.2.4 WSN Node Based on Adaptive Cuckoo Search Algorithm for Agricultural Broadcast Positioning, 2022:

In this research work [37], Xiaobing Liu has proposed a new adaptive cuckoo search algorithm is proposed to solve the problems of the standard cuckoo search algorithm, such as slow convergence rate and easy-to-get-into local optimum. Firstly, the algorithm has a large search space in the early stage and improves the global searching ability by adjusting the flight step length of Levy. Secondly, dynamic inertial weight and memory strategy are introduced for random swimming; therefore, the algorithm can make full use of historical experience and improve stability. Finally, simulation results show that the proposed algorithm can effectively improve positioning accuracy without increasing the hardware cost.

3.3. BAT ALGORITHM

The Bat algorithm had been developed in the year 2010 by Xin-She Yang to exploit the echolocation of bats. The bats make use of some sonar echoes for the detection of obstacles with sound pulses transformed into a new frequency. They navigate using time delay and emit short but loud impulses of sound. Their pulse rate is normally 10 to 20 times for each second. Once they are hit and reflected, they transform their pulse as useful information to gauge the distance of their prey. They use wavelengths varying within the range between 0.7 to 17 mm or the inbound frequencies of about 20-500 kHz. For implementing this algorithm, there was a pulse frequency with the rate that is defined. This pulse rate may be determined within the range falling between 0 and 1 wherein, 0 indicates no emission and 1 indicates the emission of the bats is at its maximum.

The behavior of bats is used for formulating the new BA.

There are three different generalized rules used while implementing these bat algorithms which are:

1. All bats make use of echolocation for sensing distances and guessing the difference between their prey and barriers of background magically.
2. While looking out for prey, bats y randomly using velocity which is vi at a position xi using the fixed frequency fmin, and a varying wavelength along with loudness of A0. The bats can adjust their wavelength automatically from emitted pulses and also adjust their pulse emission rates which is pulse emission r > [0; 1] and this is dependent on the target and its proximity.
3. Even though there can be a variation to the loudness, we will have to assume it varies from the large (positive) A0 to the minimum constant value Amin.

3.3.1. Energy efficient fuzzy clustering and routing using BAT algorithm, 2021:

In this paper [38], Lipare et al proposed a load-balanced clustering algorithm using Fuzzy C means (FCM) algorithm and an energy-efficient routing approach using the BAT algorithm (FC-RBAT). The cluster heads (CHs) are selected according to the score of the sensor node from each cluster. After the selection of the CHs, the BAT-inspired routing algorithm is applied to the CHs. The best routing path from each CH to the BS is obtained from the proposed approach. The simulations are conducted on evaluation factors such as energy consumption, active sensor nodes per round, the sustainability of the network, and the standard deviation of the load of the sensor node. It is observed that FC-RBAT outperforms compared algorithms, namely EAUCF, DUCF, and SGA, under the evaluation factors.

3.3.2. Echo Location-Based Bat Algorithm for Energy-Efficient WSN Routing, 2022:

In this paper [39], Hilal et al proposed an energy-efficient protocol using the metaheuristic Echo location-based BAT algorithm (ECHO-BAT). ECHO-BAT works in two stages. The first stage clusters the sensor nodes and identifies the tentative Cluster Head (CH) along with the entropy value using the BAT algorithm. The second stage aims to find the nodes if any, with high residual energy within each cluster. CHs will be replaced by the member node with high residual energy to choose the CH with high energy to prolong the network's lifetime. The performance of the proposed work is compared with Low-Energy Adaptive Clustering Hierarchy (LEACH), Power-Efficient Zoning Clustering Algorithm (PEZCA), and Chaotic Firefly Algorithm CH (CFACH) in terms of the lifetime of the network, death of first nodes, death of 125th node, death of the last node, network throughput and execution time. Simulation results show that ECHO-BAT outperforms the other methods in all the considered measures. The overall delivery ratio has also significantly optimized and improved by approximately 8%, proving the proposed approach to be an energy-efficient WSN.

3.3.3. An Energy-Efficient Mechanism Using Mutated Bat Algorithm in Wireless Sensor Network, 2019:

In this work [40], Maharajan and Abirami suggested the increases in energy lifetime and the stability of the network in an efficient manner within the protocols of clustering. Discussion is made on the Bat Algorithm (BA), the Bat algorithm along with mutation, and the Genetic Algorithm (GA). This BAT algorithm had search abilities with various applications to solve problems in engineering. There was viability for the mutated BAT algorithms observed in various tasks that were proven and were shown by the empirical outcomes thus making the proposed scheme perform better in comparison with all schemes.

3.4. ELEPHANT HERDING ALGORITHM

Elephants are one of the largest mammals on land. The African elephant and the Asian elephant are two traditionally recognized species. A long trunk is the most representative feature that is multipurpose, such as breathing, lifting water, and grasping objects. In nature, elephants are social animals, and they have complex social structures of females and calves. An elephant group is composed of several clans under the leadership of a matriarch, often the oldest cow clan consists of one female with her calves or certain related females. Females prefer to live in family groups, while male elephants tend to live in isolation, and they will leave their family group when growing up. Though male elephants live away from their family group, they can stay in contact with elephants in their clan through low-frequency vibrations. The herding behavior of the elephants is considered as two operators, which are subsequently idealized to form a general-purpose global optimization method.

To make the herding behavior of elephants solve all kinds of global optimization problems, we preferred to simplify it into the following idealized rules.

1) The elephant population is composed of some clans, and each clan has a fixed number of elephants.
2) A fixed number of male elephants will leave their family group and live solitarily far away from the main elephant group at each generation.
3) The elephants in each clan live together under the leadership of a matriarch.

3.4.1. Stability-aware Energy Efficient Clustering Protocol in WSN using Opposition-based Elephant Herding Optimisation,2021

In this proposed work [43], Y.Alekya Rani & E.Sreenivasa Reddy plans to derive a multi-objective function with the constraints like energy, distance, delay, stability period, and intent to attain the objective by developing a new well-performing meta-heuristic algorithm called Opposition-based Elephant Herding Optimisation (O-EHO). The objective function diminishes the energy consumption of sensor nodes by an optimum selection of cluster heads that leads to maintaining the energy balance between the normal nodes. In this way, there is a remarkable enhancement in the performance parameters such as throughput, stability period, and network lifetime. It is proved that the network lifetime is enhanced by the stability period and thus it is considered the most significant parameter. The experimental analysis proves the competitive performance of the proposed model over other heuristic methods.

3.4.2. Hybrid based Energy Efficient Cluster Head Selection using Camel Series Elephant Herding Optimization Algorithm in WSN, 2020

In this paper [42], Lavanya et al proposed a novel Camel series Elephant Herding Optimization (CSEHO) algorithm to enhance the random occurrences of the Camel algorithm by the Elephant Herding Optimization algorithm for optimal CHS. The Camel algorithm imitates the itinerant actions of a camel in the desert for the scavenging procedure. The visibility monitoring condition of the camel algorithm improves the efficiency of exploitation, whereas the exploration inefficiency of a Camel algorithm is compensated optimally by the Elephant Herding Optimization operator (Clan and separator). The superior performance of the proposed CSEHO algorithm is validated by comparing its performance with various other existing CHS algorithms. The overall attainment of the offered CSEHO algorithm is 21.01%, 31.21%, 44.08%, 67.51%, and 85.66%, better than that of EHO, CA, PSO, LEACH, and DT, respectively.

3.4.3. Elephant Herding Optimization for Energy-Based Localization, 2018

In this work [41], Sergio et al address the energy-based source localization problem in wireless sensors networks. Instead of circumventing the maximum likelihood (ML) problem by applying convex relaxations and approximations, approach it directly by the use of metaheuristics. More specifically, an elephant herding optimization (EHO) algorithm is applied. Through extensive simulations, the key parameters of the EHO algorithm are optimized such that they match the energy decay model between two sensor nodes. A detailed analysis of the computational complexity is presented, as well as a performance comparison between the proposed algorithm and existing non-metaheuristic ones. Simulation results show that the new approach significantly outperforms existing solutions in noisy environments, encouraging further improvement and testing of metaheuristic methods.

3.5. GRAY WOLF ALGORITHM

The grey wolf optimizer (GWO) represents a recent swarm intelligence algorithm proposed by Seyedali et al. in 2013. Grey wolves' hunting behavior was used as an inspiration for the GWO. The quality of the GWA was initially proved on both, benchmark and real-life optimization problems. The behavior of wolves that was incorporated into the optimization metaheuristics is that they divide into 4 distinctive classes in nature based on their dominance. Classes are named alpha, beta, delta, and omega. The most dominant group named alphas are the leaders of the pack. In the social hierarchy of the wolf pack, the lower-level wolves are in control of the upper-level pack members. In the optimization algorithm's implementation, the best solution according to the fitness function represents the leader of the pack and it is denoted as α solution; solution β is the solution that has worse

fitness function values compared to the α solution but better than all other solutions. Similarly, the third-best solution in the population is named δ. The rest of the population is in the group ω. The best solution is the prey of the wolves, and the original algorithm searches for the optimum solution in three phases that simulates the exploration and exploitation processes. Exploration was done by the encircling of prey phase; the hunting phase is refined exploration while the exploitation is done by the attacking of prey phase.

3.5.1. Enhanced Grey Wolf Algorithm for Energy-Efficient Wireless Sensor Networks,2020

In this paper [46], Miodrag Zivkovic et al proposed an improved version of the grey wolf algorithm, that has been applied to improve the network lifetime optimization. The grey wolf algorithm was employed in forming the clusters and the cluster head selection process. As a part of our research, we have evaluated the performance of the proposed exploration-enhanced grey wolf algorithm by comparing it to the traditional LEACH algorithm, basic grey wolf approach, and particle swarm optimization, which were all tested under the same experimental conditions. Obtained results from conducted simulations have proven that proposed metaheuristics perform better than other considered algorithms.

3.5.2. Grey Wolf Algorithm based Energy-Efficient Data Transmission in Internet of Things,2019

The delay and efficiency of the Internet of Things network depend upon routing mechanisms. Mukhdeep Singh Manshahia[45] presented a grey wolf algorithm-based intelligent approach in this paper for energy-efficient routing in IoT networks. A fitness function is used and simulated in MATLAB for energy-efficient data delivery in the Internet of Things. Simulation results show that the proposed approach outperforms both artificial bee colony (ABC) and artificial Fish Schooling algorithm (AFSA) in terms of network throughput and energy consumption.

3.5.3. Grey Wolf Optimization-Based Energy-Efficient Routing Protocol for Heterogeneous Wireless Sensor Networks, 2016

N. A. Al-Aboody and H. S. Al-Raweshidy [44] proposed a three-level hybrid clustering routing protocol

algorithm (MLHP) based on the Grey Wolf Optimizer (GWO) for wireless sensor networks in this paper. A centralized selection is proposed for Level One, in which the base station (BS) plays a great role in selecting cluster heads. In Level Two, a GWO routing for data transfer is proposed, where nodes select the best route to the BS to save more energy. And, a distributed clustering based on a cost function is proposed for Level Three. The algorithm was evaluated through tests of a network's energy efficiency, lifetime, and stability period. Comparisons were made with the best-known routing protocols to measure the performance of the proposed algorithm. The results showed improved performance of the proposed algorithm in terms of longer network lifetime, longer stability period, and more residual energy when compared with the other algorithms.

3.6. WHALE OPTIMIZATION ALGORITHM

The whale stochastic optimization method is making a new meta-heuristic technique that simulates the intelligence encircling prey during the hunting behavior of humpback whales. WOA is a simple, powerful, and swarm intelligence-based technique. Population-based WOA can stay away from neighborhood optima and become global optima. WOA is caused by these advantages to become the ideal algorithm for solving several constrained or perhaps unconstrained optimization trouble for functional uses with no structural reformation of the algorithm. The Metaheuristic Whale optimization technique was suggested by Mirjalili and Lewi in 2016 and aimed at optimizing numerical issues. The algorithm simulates the intelligence hunting conduct of humpback whales. This foraging action is known as encircling prey during the hunting approach which is just noticed in humpback whales. The whales produce the standard bubbles along a group road while encircling prey during hunting.

3.6.1. Energy efficient routing protocol using exponentially-ant lion whale optimization algorithm in wireless sensor networks, 2021

K. Suresh Kumar et al[49] designed using the proposed Exponentially-Ant Lion Whale Optimization (E-ALWO) algorithm to route the data packets to the receiver in this work. However, the E-ALWO algorithm is derived by the integration of the Exponentially Weighted Moving Average (EWMA) concept with Ant Lion Optimization (ALO) and Whale Optimization algorithm (WOA), respectively. However, the proposed model performs the routing process through CH such that the selection of CH is made using the ALWO algorithm based on the constraints, namely energy, and delay. The optimal and secure route used for the data transferring process is computed using the proposed E-ALWO algorithm based on the fitness measure. The fitness function considers the factors, namely energy, trust, delay, and distance. Moreover, the path with maximal fitness value is accepted as the routing path, by which the data is forwarded to the sink node through CH. The average performance measure achieved by the proposed method by considering without attack scenario in terms of delay, residual energy, throughput, and trust is 0.1484sec, 0.4998J, 42984kbps, and 0.5885.

3.6.2. Hybrid WGWO: whale grey wolf optimization-based novel energy-efficient clustering for EH-WSNs, 2020

In this paper [48], Rajkumar Singh Rathore et al presented a hybrid whale and grey wolf optimization (WGWO)-based clustering mechanism for energy harvesting wireless sensor networks (EH-WSNs). In the proposed research, they used two meta-heuristic algorithms, namely, whale and grey wolf to increase the effectiveness of the clustering mechanism. The exploitation and exploration capabilities of the proposed hybrid WGWO approach are much higher than the traditional various existing metaheuristic algorithms during the evaluation of the algorithm. This hybrid approach gives the best results. The proposed hybrid whale grey wolf optimization-based clustering mechanism consists of cluster formation and dynamic cluster head (CH) selection. The performance of the proposed scheme is compared with existing state-of-art routing protocols.

3.6.3. Whale Optimization Based Energy-Efficient Cluster Head Selection Algorithm for Wireless Sensor Networks, 2017

In this paper [47], Ashwin R Jadhav and Sankaran proposed an energy-efficient cluster head selection algorithm which is based on Whale Optimization Algorithm (WOA) called WOA-Clustering (WOA-C). Accordingly, the proposed algorithm helps in the selection of energy-aware cluster heads based on a fitness function that considers the residual energy of the node and the sum of the energy of adjacent nodes. The proposed algorithm is evaluated for network lifetime, energy efficiency, throughput, and overall stability. Furthermore, the performance of WOA-C is evaluated against other standard contemporary routing protocols such as LEACH. Extensive simulations show the superior performance of the proposed algorithm in terms of residual energy, network lifetime, and longer stability period.

3.7. FISH SWARM ALGORITHM

The fish swarm algorithm (FSA) is a new population-based/swarm intelligent evolutionary computation technique inspired by the natural schooling behavior of fish. FSA presents a strong ability to avoid local minimums to achieve global optimization. It has been proven in function optimization, Parameter estimation, combinatorial optimization, least squares support vector machine, and geotechnical engineering problems, among others. FSA imitates three typical behaviors, defined to include "searching for food", "swarming in response to a threat", and "following to increase the chance of achieving a successful result". Three major parameters involved in FSA include visual distance (*visual*), maximum step length (*step*), and a crowd factor. FSA effectiveness seems primarily influenced by the former two (*visual* and *step*).

3.7.1. Energy Effective Data Gathering in WSN: A Hybrid Approach Using K-Means And AFSO., 2021

In this work [53], Shivani S Bhasgi et al formed a dual mobile base station data gathering and mobile charging path by the artificial fish swarm optimization algorithm. The path is formed considering fitness function. The data gathering points known as summit stations are formed by using the K-means algorithm by calculating the weight function establishing complete coverage of all the nodes. The proposed method EEDG is vindicated with existing algorithms in terms of packet delivery ratio, delay, lifetime, and goodput. Results Show an increased packet delivery ratio and reduced delay when compared with existing algorithms. EEDG prolongs the lifetime by 52% more than K-means and 78% more than GEACH.

3.7.2. Proposing an Energy-Aware Routing Protocol by Using Fish Swarm Optimization Algorithm in WSN (Wireless Sensor Networks), 2021

In this paper [54], Shiva Gorgich proposed a new method that addresses the issue of optimal power consumption in WSNs. Accordingly, using the fish swarm optimization algorithm, we proposed an energy-aware routing protocol in WSNs that optimizes power consumption. The proposed protocol was simulated in OPNET 11.5 simulator and compared with the ERA protocol. Simulation results indicated that the proposed protocol had better performance than the ERA protocol regarding power consumption, end-to-end delay, media access delay, throughput rate, the probability of successful transmission to sink, and signal-to-noise ratio.

3.7.3. Energy Efficient Hybrid Routing Protocol Based on the Artificial Fish Swarm Algorithm and Ant Colony Optimization for WSNs, 2018

Xinlu Li et al [52] proposed a hybrid routing algorithm by combining the Artificial Fish Swarm Algorithm (AFSA) and ACO to address these issues. They utilized AFSA to perform the initial route discovery to find feasible routes quickly. The route discovery algorithm presented a hybrid algorithm by combining the crowd factor in AFSA and the pseudo-random route select strategy in ACO. Furthermore, this paper presents an improved pheromone update method by considering energy levels and path length. Simulation results demonstrate that the proposed algorithm avoids the routing algorithm falling into local optimization and stagnation, whilst speeding up the routing convergence, which is more prominent in a large-scale network. Furthermore, simulation evaluation reports that the proposed algorithm exhibits a significant improvement in terms of network lifetime.

3.7.4. Artificial Fish Swarm Algorithm for Energy-Efficient Routing Technique, 2015

In this work [51], Asmaa Osama Helmy et al proposed an optimized hierarchical routing technique that aims to reduce energy consumption and prolong the network lifetime. In this technique, the selection of optimal cluster heads (CHs) locations is based on Artificial Fish Swarm Algorithm (AFSA). Various behaviors in AFSA such as preying, swarming, and following are applied to select the best locations of CHs. A fitness function is used to compare these behaviors to select the best CHs. The model developed is simulated in MATLAB. Simulation results show the stability and efficiency of the proposed technique. The results are obtained in terms of the number of alive nodes and the energy residual mean value after some communication rounds. To prove the AFSA efficiency of energy consumption, we have compared it to LEACH and PSO. Simulation results show that the proposed method outperforms both LEACH and PSO in terms of first node die (FND) round, total data received by the base station, network lifetime, and energy consumption per round.

3.7.5. A Clustering Routing and Coverage Algorithm for WSN Based on Brief Artificial Fish-School Optimization, 2013

In this paper[50], Xiao, Haitao, et al described a novel clustering routing and coverage algorithm, referred to as Brief Artificial Fish-School Optimization Clustering Routing and Coverage (BAFSOCRC), for a wireless sensor network. Based on the detailed analysis of the cluster head selection algorithm and the deficiencies of the LEACH algorithm, I propose an algorithm based on Brief Artificial Fish-School Optimization (BAFSO). The key point of the clustering routing algorithm is applying the BAFSO algorithm. This algorithm can be divided into two parts: The clustering routing algorithm of WSN based on BAFSO (BAFSOCR) and the coverage of WSN based on BAFSO (BAFSOC). In the BAFSOCR, it can achieve the balance of the network energy consumption, improve the energy efficiency and prolong the life cycle of the whole network. In the BAFSOC, it can achieve distribution optimization at a higher speed with a lower cost, and increase the efficiency of the algorithm.

4. CONCLUSION AND FUTURE SCOPE

This review paper evaluated the significance of nature-inspired algorithms for energy and clustering efficiency as well as efficient routing protocols to achieve energy preservation in WSN. An artificial system based on nature-inspired species is very efficient in terms of energy preservation.

There lies an immense scope for the development and improvement of efficient cluster formation and data routing, though the published literature focuses on enhancements of various protocols. There is also a need to focus on the quality of service, inspired by natural species.

We also require to focus on the hybrid systems to optimize the problems encountered in WSN to achieve enhanced results. These hybrid systems can offer new dimensions to uncover optimal solutions for WSNs.

Our extensive review will aid researchers to understand the most recent accomplishments in the field of nature-inspired routing for real-world problems for energy optimization in WSN

REFERENCES:

[1] Yuebin Bai, Shujuan Liu, Mo Sha, Yang Lu, and Cong Xu, "An Energy Optimization Protocol Based on Cross-Layer for Wireless Sensor Networks", Journal of Communications, Vol. 3, No. 6, pp. 27-34, 2008.

[2] C. Umamaheswari and J. Gnanambigai, "Energy Optimization in Wireless Sensor Network Using Sleep Mode Transceiver", Global Journals of Research Engineering, Vol. 11, No. 3, pp. 1-6, 2011.

[3] M.L. Sichitiu and N.C. Raleigh, "Cross-Layer Scheduling for Power Efficiency in Wireless Sensor Networks", Proceedings of 23rd Annual Joint Conference of the IEEE Computer and Communication Societies, Vol. 3, pp. 1740-1750, 2004.

[4] Wei Yei, John Heidemann and Deborach Estrin, "An Energy-Efficient Mac Protocol for Wireless Sensor Networks", Proceedings of 21st Annual Joint Conference of the IEEE Computer and Communication Societies, Vol. 3, pp. 1567-1576, 2002.

[5] R. Wattenhofer, L. Li, P. Bahl and Y-M. Wang, "Distributed Topology Control for Power Efficient Operation in Multihop Wireless Ad Hoc Networks", Proceedings of 20th Annual Joint Conference of the IEEE Computer and Communications Societies, Vol. 3, pp. 1388-1397, 2001.

[6] Gianni Di Caro and Marco Dorigo, "Ant Colonies for Adaptive Routing in Packet Switched Communications Networks", Proceedings of the 5th International Conference on Parallel Problem Solving from Nature, pp. 673-682, 1998.

[7] Muhammad Saleem and Muddassar Farooq, "BeeSensor: A Bee-Inspired Power Aware Routing Protocol for Wireless Sensor Networks", Proceedings of the EvoWorkshops: Application of Evolutionary Computing, pp. 81-90, 2007.

[8] Sanjeev Wagh and Ramjee Prasad, "Energy Optimization in Wireless Sensor Network through Natural Science Computing: A Survey", Journal of Green Engineering, Vol. 3, No. 4, pp. 383-402, 2013.

[9] Alberto Colorni, Marco Dorigo and Vittorio Maniezzo, “Distributed Optimization by Ant Colonies”, Proceedings of the First European Conference on Artificial Life, Vol. 142, pp. 134-142, 1991.
[10] Marco Dorigo, “Optimization, Learning, and Natural Algorithms", Ph.D. Thesis, Department of Electronics, Politecnico di Milano, Italy, 1992.
[11] Wang Guifeng, Wang Yong and Tao Xiaoling, “An Ant Colony Clustering Routing Algorithm for Wireless Sensor Networks”, Proceedings of 3rd International Conference on Genetic and Evolutionary Computing, pp. 670-673, 2009.
[12] M. Ziyadi, K. Yasami, and B. Abolhassani, "Adaptive Clustering for Energy Efficient Wireless Sensor Networks Based on Ant Colony Optimization”, Proceedings of the 7th Annual Communication Networks and Services Research Conference, pp. 330-334, 2009.
[13] Lin Wang, Ruihua Zhang and Shichao Geng, “An Energy-Balanced Ant-Based Routing Protocol for Wireless Sensor Networks”, Proceedings of 5th International Conference on Wireless Communications, Networking and Mobile Computing, pp. 1-4, 2009.
[14] Dali Wei, Yichao Jin, S. Vural, K. Moessner, and R. Tafazolli, "An Energy Efficient Clustering Solution for WSNs”, IEEE Transactions on Wireless Communications, Vol. 10, No. 11, pp. 3973-3983, 2011.
[15] Junlei Bi, Zhiyuan Li, and Ruchuan Wang, "An Ant Colony Optimization-Based Load Balancing Routing Algorithm for Wireless Multimedia Sensor Networks”, Proceedings of the 12th IEEE International Conference on Communication Technology, pp. 584-587, 2010.
[16] Zhenchao Wang, Xin Jing, and Jing Wang, "A Novel Routing Algorithm Based on Ant Colony Optimization for Hierarchical Wireless Sensor Networks”, Proceedings of International Conference in Electrics, Communication and Automatic Control, pp. 825-831, 2011.
[17] K. Syed Ali Fathima and K. Sindhanaiselvan, “Ant Colony Optimization Based Routing in WSNs”, International Journal of Advanced Networking and Applications, Vol. 4, No. 4, pp. 1686-1689, 2013.
[18] Soumitra Das and Sanjeev Wagh, “Prolonging the Lifetime of the Wireless Sensor Network Based on Blending of Genetic Algorithm and Ant Colony Optimization”, Journal of Green Engineering, Vol. 4, No. 3, pp. 245-260, 2015.
[19] Peng Li1,2, Huqing Nie1, LingfengQiu1, and RuchuanWang, “Energy optimization of ant colony algorithm in wireless sensor network”, International Journal of Distributed Sensor Networks 2017, Vol. 13(4)
[20] K.F. Man, K.S. Tang, and S. Kwong, “Genetic Algorithms: Concepts and Applications”, IEEE Transactions on Industrial Electronics, Vol. 43, No. 5, pp. 519-534, 1996.
[21] Sudakshina Dasgupta and Paramartha Dutta, “An Energy Efficient Genetic Approach for Clustering of Wireless Sensor Networks”, International Journal of Information and Electronics Engineering, Vol. 2, No. 2, pp. 54-58, 2012.
[22] Mehr Moslem Afrashteh, “Design and Implementation a New Energy Efficient Clustering Algorithm Using Genetic Algorithm for Wireless Sensor Networks”, World Academy of Science, Engineering, and Technology, Vol. 5, No. 4, pp. 373-376, 2011.
[23] Jianming Zhang,Yaping Lin, Cuihong Zhou, and Jingcheng Ouyang, "Optimal Model for Energy-Efficient Clustering in Wireless Sensor Networks Using Global Simulated Annealing Genetic Algorithm”, Proceedings of International Symposium on Intelligent Information Technology Application Workshops, pp. 656-660, 2008.
[24] Selim Bayrakli and Senol Zafer Erdogan, "Genetic Algorithm Based Energy Efficient Clusters (GABEEC) in Wireless Sensor Networks”, Procedia Computer Science, Vol. 10, pp. 247-254, 2012.
[25] D. Srinivasa Rao and B.J.M. Ravi Kumar, “Performance Evaluation of Genetic Based Dynamic Clustering Algorithm over LEACH Algorithm for Wireless Sensor Networks”, International Journal of Soft Computing and Engineering, Vol. 1, No. 4, pp. 233-236, 2011.
[26] Sanjeev Wagh and Ramjee Prasad, “Heuristic Clustering for Wireless Sensor Networks Using Genetic Approach”, International Journal of Wireless and Mobile Networks, Vol. 1, No. 1, pp. 51-62, 2013.
[27] Mohammad M. Shurman, Mamoun F. Al-Mistarihi, Amr N. Mohammad, Khalid A. Darabkh and Ahmad A. Ababnah, “Hierarchical Clustering Using Genetic Algorithm in Wireless Sensor Networks”, Proceedings of 36th Jubilee International Convention on Information and Communication Technology, Electronics, and Microelectronics, 2013.
[28] Nivedita B. Nimbalkar, Soumitra S. Das and Sanjeev J. Wagh, “Trust Based Energy Efficient Clustering Using Genetic Algorithm in Wireless Sensor Networks”,
International Journal of Computer Applications, Vol. 112, No. 9, pp. 30-33, 2015.
[29] Xin-She Yang and S. Deb, “Cuckoo Search via Lévy Flights”, World Congress on Nature & Biologically Inspired Computing, pp. 210-214, 2009.
[30] R.B. Payne, M. D. Sorenson, and K. Klitz, "The Cuckoos”, Oxford University Press, 2005.
[31] Manian Dhivya, Murugesan Sundarambal and Loganathan Nithissh Anand, “Energy Efficient Computation of Data Fusion in Wireless Sensor Networks using Cuckoo based Particle Approach (CBPA)”, International Journal of Communications, Network and System Sciences, Vol. 4, No. 4, pp. 249-255, 2011.
[32] Manian Dhivya, Murugesan Sundarambal and J. Oswald Vincent, “Energy Efficient Cluster Formation in Wireless Sensor Networks using Cuckoo Search”, Proceedings of 2nd International Conference on Swarm, Evolutionary and Memetic Computing, Vol. Part II, pp. 140-147, 2011.
[33] D. Antony Arul Raj and P. Sumathi, “Enhanced Energy Efficient Multipath Routing Protocol for Wireless Sensor Communication Networks using Cuckoo Search Algorithm”, Wireless Sensor Network, Vol. 6, pp 49-55, 2014.
[34] Gurpreet Kaur Bhatti and Jatinder Pal Singh Raina, “Cuckoo-based Energy Effective Routing in Wireless Sensor Network”, International Journal of Computer Science and Communication Engineering, Vol. 3, No. 1, pp. 92-95, 2014.

[35] E. Sandeep Kumar, G.P. Mohanraj and Raghuchandra R. Goudar, "Clustering Approach for Wireless Sensor Networks Based on Cuckoo Search Strategy", International Journal of Advanced Research in Computer and Communication Engineering, Vol. 3, No. 6, pp. 6966-6970, 2014.
[36] Govind P.Gupta, "Improved Cuckoo search-based Clustering protocol for Wireless Sensor Networks, "6th International Conference on Smart Computing and Communications 2018
10.1016/j.procs.2017.12.032.
[37] Xiaobing Liu, "WSN Node Based on Adaptive Cuckoo Search Algorithm for Agricultural Broadcast Positioning" Journal of Cases on Information Technology Volume 24 • Issue 5.2022
[38] Anwer Mustafa Hilal, Siwar Ben Haj Hassine, Jaber S. Alzahrani, Masoud Alajmi,
Fahd N. Al-Wesabi, Mesfer Al Duhayyim6, Ishfaq Yaseen1, and Abdelwahed Motwakel, "Echo Location Based Bat Algorithm for Energy Efficient WSN Routing" Computers, Materials & Continua2022.
[39] Amruta Lipare, Damodar Reddy Edla. Ramesh Dharavath, "Energy efficient fuzzy clustering and routing using BAT algorithm", Wireless Networks, part of Springer Nature 2021
[40] Mr.Maharajan M S, T.Abirami, "An Energy Efficient Mechanism using Mutated
Bat Algorithm in Wireless Sensor Network", International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-8 Issue-11, September 2019
[41] Sérgio D. Correia, Marko Beko, Luis A. da Silva Cruz, and Slavisa Tomic," Elephant Herding Optimization for Energy-Based Localization Sensors 2018.
[42] N. Lavanya, T. Shankar, "Hybrid-based Energy Efficient Cluster Head Selection using Camel Series Elephant Herding Optimization Algorithm in WSN" (IJACSA) International Journal of Advanced Computer Science and Applications, Vol. 11, No. 5, 2020.
[43] Y. Alekya Rani & E. Sreenivasa Reddy, "Stability-aware Energy Efficient Clustering Protocol
in WSN using Opposition-based Elephant Herding Optimisation", Journal of Control and Decision 2021.
[44] N. A. Al-Aboody and H. S. Al-Raweshidy," Grey Wolf Optimization-Based Energy-Efficient Routing Protocol for Heterogeneous Wireless Sensor Networks", 4th International Symposium on Computational and Business Intelligence 2016.
[45] Mukhdeep Singh Manshahia, "Grey Wolf Algorithm based Energy-Efficient Data Transmission in Internet of Things", The 6th International Symposium on Emerging Information, Communication and Networks (EICN 2019).
[46] Miodrag Zivkovic, Nebojsa Bacanin, Tamara Zivkovic, Ivana Strumberger, Eva Tuba, Milan Tuba, "Enhanced Grey Wolf Algorithm for Energy Efficient Wireless Sensor Networks" IEEE Xplore 2020
[47] Ashwin R Jadhav, T.Shankar, " Whale Optimization Based Energy-Efficient Cluster Head Selection Algorithm for Wireless Sensor Networks", Journal of Neural and Evolutionary Computing,2017.
[48] Rajkumar Singh Rathore, Suman Sangwan, Shiv Prakash, Kabita Adhikari, Rupak Kharel and Yue Cao, "Hybrid WGWO: whale grey wolf optimization-based novel energy-efficient clustering for EH-WSNs" Journal on Wireless Communications and Networking,2020.
[49] K. Suresh Kumar, P. Vimala, "Energy efficient routing protocol using exponentially-ant lion whale
optimization algorithm in wireless sensor networks" Journal of Computer Networks,2021.
[50] Xiao, Haitao; Zhao, Xue; Ogai, Harutoshi, "Energy efficient routing protocol using exponentially-ant lion whale optimization algorithm in wireless sensor networks" Sensor Letters, Volume 11, Number 4, April 2013, pp. 697-703(7).
[51] Asmaa Osama Helmy, Shaimaa Ahmed, and Aboul Ella Hassenian, "Artificial Fish Swarm Algorithm for Energy-Efficient Routing Technique", Advances in Intelligent Systems and Computing 2015.
[52] Xinlu Li, Brian Keegan, and Fredrick Mtenzi, "Energy Efficient Hybrid Routing Protocol Based on
the Artificial Fish Swarm Algorithm and Ant Colony Optimisation for WSNs". Sensors 2018, 18, 3351.
[53] Shivani S Bhasgi, Sujatha Terdal. "Energy Effective Data Gathering In Wsn: A Hybrid Approach Using K-Means And AFSO", Turkish Journal of Computer and Mathematics Education,2021.
[54] Shiva Gorgich· Shayesteh Tabatabaei, "Proposing an Energy-Aware Routing Protocol by Using Fish
Swarm Optimization Algorithm in WSN (Wireless Sensor Networks)", Wireless Personal Communications (2021) 119:1935–1955.