Use of Various Optimization Algorithms in the Energy Minimization Problem Domain of WSN: A Survey

Sudip Kumar De, Avishek Banerjee, Koushik Majumder, Rabindra Nath Shaw, and Ankush Ghosh

Abstract A wireless sensor network (WSN) is a collection of sensor nodes that are geographically distributed and wirelessly connected. A wireless sensor node is a small device that can sense various physical measurements from its environment and after converting them into electrical signals it can send and receive a limited quantity of data to other nodes or a sink node in the network. The sensed data is used to facilitate the users in different ways. A wireless sensor node typically contains a microcontroller unit (responsible for processing), a transceiver unit (responsible for communication), a data storage unit (responsible for storing information), one or more sensors, and a battery stored power unit (responsible for supplying energy to other units). The power storage capability of the small battery is quite limited. If the use of energy is not prioritized for the supplementation of energy to various components, a WSN might soon dry out. One of the prime focuses of researchers in the field of WSN is the minimization of energy. If the energy can be minimized then the sustainability of the network will be maximized. In this paper, the energy minimization problem has been addressed along with the usage of optimization algorithms.

Keywords Wireless sensor network (WSN) · Energy management strategies · Deployment · Clustering · Duty cycle · Data aggregation · Optimization algorithms

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1 Introduction

A wireless sensor network (WSN) is a self-contained network with several nodes and a few controllers known as sink nodes. The processing unit, a communication unit, memory unit, sensor unit, and battery unit are the five major but small units that make up the WSN nodes. The sensor unit detects various types of external analog signals, the processing unit processes the data and converts it to processed data, the memory unit stores the processed data, and the communication unit establishes connections between neighboring nodes. The battery unit is responsible for providing power to the entire node.

Wireless sensor networks (WSNs) have grown in popularity in recent years as a result of industry 4.0-related research for a variety of reasons. The following are some of the benefits of employing WSNs in Industry 4.0.

1. **Deployability**: Due to the ease with which WSN nodes and sink nodes can be deployed, WSN is being used in a variety of technical applications, such as pressure and temperature in a blast furnace, where human intervention is difficult.
2. **Accessibility**: This attribute allows the network to be accessed easily through a strong connection model using WSN nodes and sink nodes, though hardware reliance is a major aspect that influences the network's accessibility.
3. **Commercialization**: In the recent era, the commercialization of WSN nodes has also been an advantage in terms of easy availability of the essential equipment to build a powerful networking system.

Though the WSN has some drawbacks, such as limited computing capability due to its small designs, limited communication range between two neighboring nodes, and limited sensing capacity of coupled sensors, it has a lot of potentials. Despite its limitations, the WSN performs admirably in a variety of challenging situations. Many optimizations and soft computing techniques have been developed by the researchers to overcome challenges in a variety of areas, including coverage area optimization, power consumption optimization, duty cycle optimization, routing protocol optimization, topology control optimization, cost optimization, and so on.

Motivation: Various optimization techniques for energy management strategies in WSNs have been investigated in this survey, which will be useful to researchers. The authors considered 37 research articles from the year 2000 to the present for the descriptive analysis on energy management strategies, as shown in Fig. 1.

2 Existing Energy Management Strategies in WSN

The energy management strategies in WSN can be classified as:

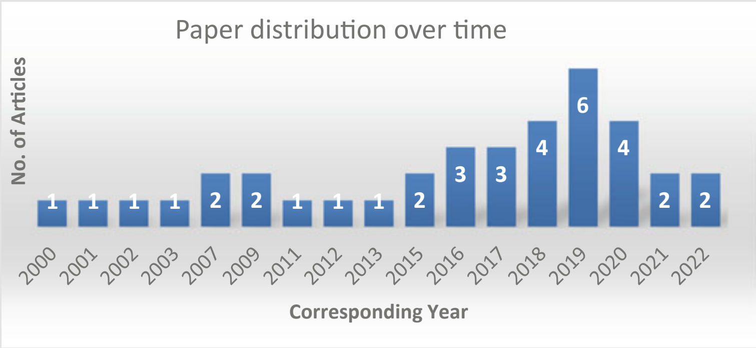
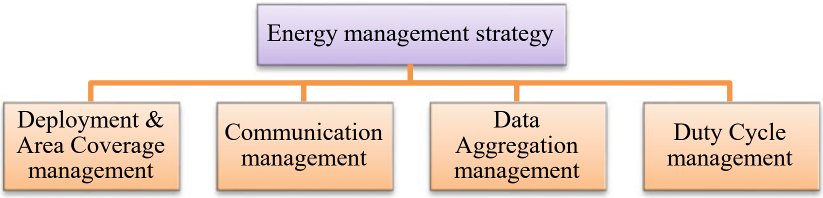


Fig. 1 Paper distribution over time



2.1 Deployment and Area Coverage Management

Wireless sensor node deployment entails dispersing active WSN nodes throughout a target region. The deployment approach might be planned or haphazard. The haphazard or random deployment of WSN nodes increases the number of redundant nodes, whereas the planned node deployment strategy can reduce redundant nodes. Even with a significant number of redundant nodes deployed, coverage excellence cannot be assured. The deployment approach has a direct impact on the coverage quality of the network, network communication, and energy requirements of the network. The area coverage parameter of the WSN focuses on how adequately a target region is tracked. The coverage quality has a considerable impact on the functioning of a wireless sensor network (WSN) system. The network's energy requirements may be minimized with an optimal deployment strategy, allowing it to last longer. The energy minimized sensor deployment strategy is an NP-complete problem. For that reason, researchers are trying to use metaheuristic algorithms to get optimal or near-optimal solutions.

In 2021, Banerjee et al. [1] proposed different deployment strategies (random deployment, S-pattern and Spiral-pattern) to minimize the consumed energy by WSN nodes. The DE-QPSO, a hybrid algorithm with a single objective function, was utilized to build an energy-efficient network.

In 2019, Wang et al. [2] proposed two flower pollination algorithms (FPA): The first is an improved flower pollination algorithm (IFPA) that improves the FPA algorithm's convergence speed and precision; the second is a non-dominated sorting multi-objective flower pollination algorithm (NSMOFPA) based on FPA that effectively maintains population diversity. The NSMOFPA optimization method results in a more optimal WSN deployment in terms of energy consumption, coverage area, etc.

In 2017, Benatia et al. [3] proposed a multi-objective genetic algorithm (GA) to develop a multi-objective optimization deployment strategy (MODS). In this paper, the authors had proved that energy consumption directly depends on the distance between the sink node and WSN node. And the distance between WSN nodes and the sink node can be optimized using an effective deployment strategy which will help in the optimization of the WSN lifetime.

In 2018, Céspedes-Mota et al. [4] proposed a multi-objective differential evolution algorithm (MODEA) to optimize the sensor deployment process over the target area for the maximization of area coverage and minimization of the network's energy consumptions. It shows a good result; however, the research does not take into account the energy consumption caused by data communication: transmission and reception.

In 2019, Xiang et al. [5] suggested a hybrid node deployment approach employing the cuckoo search (CS) metaheuristic algorithm, and it was discovered that their optimization technique can both minimize energy consumption and improve coverage area. According to the authors they claim that their algorithm can balance the regional coverage and energy consumption. The authors had considered moveable WSN nodes. Their focus was on minimizing the number of movements of the WSN nodes. If the number of movements is reduced then the energy loss in process of movement will be also reduced. And this approach helped them to minimize the energy requirement of the network. But the relationship between the energy loss and node movement process is not depicted in the paper.

In 2020, ZainEldin et al. [6] have proposed a deployment strategy using a multi-objective metaheuristic algorithm, IDDTGA. The genetic algorithm (GA) has been used to find the optimal locations of the WSN nodes considering the mobility feature of the WSN nodes to reduce the coverage hole. The main focus of the paper is to develop an improved deployment strategy to minimize the network cost by minimizing WSN nodes with the greatest possible coverage area.

In 2022, Banerjee et al. [7] have proposed the algorithm for the construction of an energy-efficient WSN. The authors have used the Least Distance Connect First (LDCF) deployment strategy with the K-Mean algorithm and a hybrid algorithm, GA-SAMP-MWPSO, to minimize the overall energy requirement of the network. The algorithm delivers a better outcome than the existing algorithms (ACO, GA, PSO).

2.2 Communication Management

The data, collected from various nodes, should be transmitted to the sink node through the network. This data transfer requires a significant amount of battery power. Researchers have shown their interest to develop energy-efficient WSN communication management strategies. *Clustering and routing algorithms, as well as MAC protocol design*, are used in communication management methods to construct an energy-efficient WSN. To build an energy-efficient WSN communication strategy, one should concentrate on the factors like conserved battery power, energy dissipation rate, amount of energy harvesting from various activities such as vibrations, light, temperature, etc., collision avoidance rate, latency degradation rate, packet loss rate, avoidance of data redundancy, efficient routing with proper bandwidth utilization and so on.

The MAC protocol design can be classified as contention-based [8], contention-free [9], non-collision-based [10]. The contention-based allows several nodes to share the same radio channel without prior cooperation. The contention-free protocol typically uses the time division multiplexing access (TDMA) technique and relies on the fact that all the nodes are synchronized with time. It works well for the small network but for the larger network, the synchronization of the time is not always feasible. Although the CSMA/CD, CSMA/CA protocol eliminates collisions once a node has obtained a channel, collisions can still occur if many nodes begin sending data at the same time. A non-collision-based protocol resolves collision in the contention period to eliminate the chance of collision.

Although optimization techniques were less utilized in the design of the energy-efficient MAC protocol, they were widely used in clustering and routing algorithms to construct energy-efficient networks.

Ye et al. [8] designed the S-MAC protocol, which is specifically developed for wireless communication networks. The authors identified a few causes of energy wastage: the collision of packets, packet overhearing, controlling the less useful packet sending overhead, idle packet listening. If the above factors are considered then an energy-efficient network can be designed. It has been stated that a collision causes data to be resubmitted, and data resubmission increases communication delay as well as energy needs. When a WSN node picks up packets that are supposed to be for other WSN nodes then this thing is known as overhearing, and this overhearing of data can lead to an inefficient design of the network because this is another reason for energy loss. Having good control over less useful or most useful packets screening leads to an energy-efficient network. The result shows that the S-MAC protocol saves more energy compared to the energy used by the 802.11-like MAC protocol.

Rajendran et al. [10] developed Traffic-Adaptive Medium Access (TRAMA), a noble protocol that delivers collision-free unicast, multicast, broadcast transmission by managing the idle packet listening factor and employing transmission schedules to avoid collisions. It is stated that when the transmission load in a contention-based system, such as S-MAC, grows, the risk of packet collision increases, lowering channel utilization and wasting battery power. The TRAMA protocol can be useful to design an energy-efficient WSN.

Alvi et al. [9] suggested a non-collision-based protocol that combines the Knapsack optimization method with a contention-free or TDMA-based protocol for better link utilization. By minimizing the control overhead by assigning 1 byte short ID to every node, energy consumption is also reduced.

Clustering is the process of splitting a region of interest into several subregions, or clusters. One of the most important strategies for extending the life of a network is clustering. Routing is the process of finding routes or paths for the transferring of the data from the source node to the destination. Both clustering algorithms and routing algorithms have a significant influence on the energy minimization process of WSN.

Heinzelman et al. [11] had proposed a cluster-based communication protocol, low-energy adaptive clustering hierarchy (LEACH). This algorithm distributes energy load at random and integrates data fusion into the routing protocol to reduce overall network energy consumption. The LEACH algorithm provides Quality of Service (QoS) while also extending the network's lifespan. The LEACH routing protocol has been designed considering single-hop connectivity between CH and base station (BS). When the coverage area is large, then the distance between the CH and base station might not be appropriate for LEACH routing using single-Hop communication. To address this issue the multi-hop LEACH protocol has been proposed by Biradar et al. [12]. The multi-hop LEACH shows energy efficiency in WSN.

Manjeshwar et al. [13] had proposed a hierarchical cluster-based communication protocol, threshold-sensitive energy-efficient sensor network protocol (TEEN), for reactive (quick response time) WSNs which are suitable for real-time or time-constrained applications and which shows efficiency in energy consumption.

In 2007, Latiff et al. [14] applied the particle swarm optimization (PSO) metaheuristic algorithm for optimization of energy consumption of the network. Using this optimization algorithm, the network's lifetime has been increased. It also shows that the PSO outperforms both LEACH and LEACH-C in terms of network coverage and total throughput.

In 2016, Vimalarani et al. [15] had proposed an enhanced PSO-based clustering energy optimization (EPSO-CEO) algorithm. The authors employed the enhanced PSO optimization algorithm to create clusters and to choose optimal cluster heads from the clusters. To evaluate the algorithm, authors had considered these factors: packet delivery ratio, packet dropping ratio, end-to-end latency, throughput, total residual energy, average residual energy, total energy consumption, and the simulation results prove that the authors' approach is better than the competitive clustering (CC) algorithm.

Saha and Gupta [16] try to address the problem of cluster head (CH) selection to solve the energy hole problem using harmony search-based clustering protocol. To minimize energy consumption, the thought of the mobile sink nodes has been introduced. When compared to the LEACH algorithm, it shows to be a superior method in terms of energy usage and the number of alive nodes.

Arjunan and Sujatha [17] introduced a hybrid optimization approach that combines a fuzzy logic-based cluster scheme with the ant colony optimization (ACO) technique. It has been compared with the existing protocols LEACH, TEEN, DEEC, etc. and it has been found that their hybridized algorithm works better than the existing protocols LEACH, TEEN, DEEC in terms of energy consumption, number of alive nodes. It eliminates the energy hole problem of the network.

In 2018 Javadpour et al. [18] also proposed an energy-efficient clustering algorithm using fuzzy logic and PSO algorithm. The fuzzy logic has been used to build the network and PSO has been used to choose the cluster head. This strategy extends the network's life by reducing the amount of energy required by the sensor network.

Krishnan et al. [19] proposed an enhanced energy-efficient clustering algorithm using the ACO optimization algorithm considering multiple mobile sink nodes for maximizing the energy efficiency of the network. This ACO-based algorithm outperforms LEACH, GA, and PSO and shows the maximization of the lifetime with reduced data loss.

Wang et al. [20] have proposed an enhanced PSO algorithm to a search of energy centers for cluster head (CH) selection. This approach tackles the problem of energy holes in the network, and it outperforms the other algorithm (VD-PSO) in terms of energy usage and network lifetime.

Vijayalakshmi and Anandan [21] proposed a multi-objective optimization algorithm, Tabu particle swarm optimization, by hybridizing simple PSO and generalized Tabu search algorithms. The distance between nodes and BS, as well as the energy level of nodes, were taken into account when designing the multi-objective problem. The PSO has been applied to find the local best position of the base station (BS). To find the global best position the hybridized Tabu-PSO algorithm has been applied. In terms of the number of alive nodes, packet loss rate, and average latency, the findings reveal that Tab-PSO beats the multi-hop-LEACH and PSO algorithms.

Anand and Pandey [22] proposed a GA-PSO algorithm to maximize the network's lifetime. For each cluster, a cluster head (CH) is determined using the GA method, which took into account the node's distance and energy factors. The selection of relay nodes is based on a genetic approach in which the first CHs are picked and a subset of cluster heads is designated as relay nodes. When a CH has data to send to a base station (BS) or sink node (SN), it will use the best routing paths using the PSO algorithm to send it to the BS through the relay nodes or directly to the BS. The network lifetime rises as a result of improved CH selection and relay nodes deployment strategy in the network. The GA-PSO algorithm outperforms other standard methods such as LEACH, HCR, GADA-LEACH, and EA-CRP.

Deepa and Suguna [23] proposed OQoS-CMRP, a cluster-based multipath routing protocol, to minimize network energy consumption by minimizing communication overhead and transmission latency. The authors employed a modified PSO metaheuristic algorithm to create clusters, choose cluster heads, and solve energy hole problems.

Banerjee et al. [7] employed a modified K-Mean method in 2022 to determine the position of the sink node (SN) during the clusterization process. Later, to extend the network's lifespan, the hybridized algorithm GA-SAMP-MWPSO was applied.

In 2021, Banerjee et al. [24] suggested a modified ACO technique to create an energy-efficient smart WSN system in a smart city by minimizing the coverage path. They have chosen an area of Durgapur, India, as an experimental zone (3.62 × 3.62 km^2) where the information related to longitude, latitude has been fetched from http://overpass-api.de/api. Their routing strategy brings lifetime enhancement to the network.

2.3 Data Aggregation Strategy

Data gathered by many WSN nodes are sent to the cluster head (CH), and subsequently from the cluster head to the base station (BS) using a multi-hop or single-hop architecture. There is always a possibility of redundant data transmission. Data aggregation is a process that extends the lifetime of a WSN node by eliminating redundant unnecessary data and reducing the number of transmissions. Minimizing the length of the data packet network's lifetime can also be maximized. Dhasian et al. [25] divided data aggregation into five categories: network-based, cluster-based, tree-based, and centralized aggregation.

Al-Karaki et al. [26] have proposed a **network-based** data aggregation strategy, grid-based routing and aggregator selection scheme (GRASS), to minimize the energy consumptions of the network. To prolong the lifetime of the network the authors have used the genetic algorithm (GA) for finding data aggregation points, routes from WSN nodes to the data aggregation points, and the route from data aggregation point to the base station. Their twin heuristic approach in routing as well as data aggregation improves network longevity.

In **cluster-based** aggregation, sensor-sensed data is sent to cluster head (CH) and after aggregating the received data, CH sends the data to the base station (BS). In cluster-based data aggregation, intra-cluster data redundancy mainly happens and it consumes less energy, but it suffers from low accuracy and high latency problems when a large number of packets arrive in a short period. Shao-liang et al. [27], LEACH, HEED are popular cluster-based data aggregation algorithms.

Lu et al. [28] have proposed a probabilistic **tree-based** aggregation protocol using the hybridization of two optimization algorithms: ant colony optimization (ACO) and genetic algorithm (GA). The applied multi-objective function takes into account four goals: reducing energy usage, lowering aggregation delay, minimizing transmission interference, and maximizing network longevity. Using ACO-GA, the routing scheme has been developed. Packets received at nodes become deterministic when an adaptive dynamic timer policy is used in the routing process. The dynamic timer strategy reduces transmission delay and increases the likelihood of data aggregation. Yu et al. [29] have proposed a distributed tree-base data aggregation algorithm to reduce aggregation latency using a collision-free scheduling greedy approach.

Xiao et al. [30] suggested a **centralized** data aggregation technique. They have given their focus on energy allocation schemes centrally to minimize the energy requirement of the network. To get the optimum value of accuracy for the data aggregation, the heuristical genetic approach has been adopted.

2.4 Duty Cycle Management

Duty cycle management is another important factor for the durability of the WSN. The power supply to the WSN nodes is limited. As a result, nodes cannot constantly remain in an active state since they would dry out very quickly. The ratio of a sensor node's active phase to its sleep phase is referred to as the duty cycle. By optimizing the duty cycle of WSN nodes, network's lifetime can be extended.

De Paz Alberola and Pesch [31] developed a duty cycle management algorithm, DCLA, that estimates the ideal duty cycle using the reinforcement learning (RL) technique. The RL collects the network's analytical data (delay constraints and the likelihood of successful data delivery) to forecast incoming traffic demand. It has been found that DCLA can minimize energy consumption while also having low processing power and memory demand capabilities.

Sinde et al. [32] proposed an algorithm, E^2S-DRL, which has three phases: clustering phase, duty cycle management phase, and routing phase. The algorithm's goal is to reduce the network's energy consumption while also increasing its longevity. During the clustering phase, they concentrated on the data aggregation method while performing zone-based clustering with a hybrid PSO and affinity propagation (AP) algorithms. In the second phase, deep reinforcement learning (DRL) has been applied for duty cycle management. In the third phase, ACO and firefly algorithm (FFA) have been used to find the route of communication while keeping transmission latency in mind. The DRL method is used to adaptively plan the scheduling modes (sleep, listen, and transmit) of each sensor node, and it ensures that each WSN node will have a unique time slot to avoid data collision during communication.

Xu et al. [33] proposed a hybrid optimization algorithm, PHGWO, to address the problem of duty cycle management for the minimization of energy consumption. The parallel operator has been used with the gray wolf algorithm, and it is noticed that the hybrid algorithm, PHGWO, performs better than GA, PSO algorithms in terms of energy consumptions of the network.

Liu et al. [34] presented QCGWO, a hybrid algorithm for extending network lifetime by optimizing sensor duty cycle while taking into account real-world factory circumstances. The integration of quantum computing with gray wolf optimization assists the QCGWO in avoiding a local optimum. When it comes to enhancing network lifetime, the QCGWO algorithm surpasses the GA and simulated annealing (SA) techniques.

Subramanian and Paramasivam [35] proposed a MAC-based QoS algorithm, by applying the concept of assigning priorities among the nodes (PRIN) while considering the factors like delay, energy requirement, the lifespan of the network. They attempted to minimize the sensor nodes' duty cycle to extend the network's lifespan.

Iala et al. [36] proposed an adaptive duty cycle protocol (AD-MAC) to reduce energy consumption where the transceiver is waiting for incoming packets by estimating the time frame of incoming data packets. As the AD-MAC does not need central synchronization so the scalability factor of this approach is high. In terms of minimizing energy usage and successful data delivery report, the AD-MAC protocol beats the IEEE 802.15.4 standard.

Khan et al. [37] developed a dynamic adaptive duty cycle algorithm that works in complex and dynamic environments without the need for external assistance. Using ANN, they predict the timeframe pattern of incoming data packets at which the receiver should be in an active state. Comparing the results of the dynamic adaptive duty cycle algorithm with the fixed duty cycle algorithm it has been observed that ANN-based dynamic adaptive duty cycle algorithm minimizes the overall energy requirement [38].

3 Conclusions

The construction of an energy-efficient WSN is always a great challenging task. Lots of factors can be considered to build an energy-efficient WSN. After examining the research articles on deployment methods, it was discovered that there are more types of deployment techniques that may be developed to reduce the WSN energy consumption. Many researchers had worked on the maximization of coverage area. By maximizing the coverage area, one can save the number of WSN nodes to be deployed. To reduce the total energy consumption in WSN transmission, researchers can use ANN to build efficient communication routes in the WSN. The researcher can concentrate on developing lossless data aggregation algorithms based on compressive sensing. The compressed data can be retrieved at the receiver's end if the data aggregation approach is lossless. If the pattern of sleep and wake states of WSN can be predicted in advance using ANN, SVM, or other sorts of decision-making algorithms, then the energy-minimized WSN can be constructed with minimum latency.

References

1. Banerjee, A., Das, V., Biswas, A., Chattopadhyay, S., Biswas, U.: Development of energy-efficient and optimized coverage area network configuration to achieve reliable WSN network using meta-heuristic approaches. Int. J. Appl. Metaheuristic Comput. (IJAMC) **12**(3), Article 1 (2021)
2. Wang, Z., Xie, H., He, D., Chan, S.: Wireless sensor network deployment optimization based on two flower pollination algorithms. IEEE Access **7**, 180590–180608 (2019)
3. Benatia, M.A., Baudry, D., Louis, A., El-Hami, A., Mazari, B.: Multi-objective WSN deployment using genetic algorithms under cost, coverage, and connectivity constraints. Wireless Pers. Commun. **94**(4), 2739–2768 (2017)
4. Céspedes-Mota, A., Castañón, G., Martínez-Herrera, A.F., Cárdenas-Barrón, L.E., Sarmiento, A.M.: Differential evolution algorithm applied to wireless sensor distribution on different

geometric shapes with area and energy optimization. J. Netw. Comput. Appl. **119**, 14–23 (2018)
5. Xiang, T., Wang, H., Shi, Y.: Hybrid WSN node deployment optimization strategy based on CS algorithm. In: 2019 IEEE 3rd Information Technology, Networking, Electronic and Automation Control Conference (ITNEC), pp. 621–625. IEEE (2019)
6. ZainEldin, H., Badawy, M., Elhosseini, M., Arafat, H., Abraham, A.: An improved dynamic deployment technique based-on genetic algorithm (IDDT-GA) for maximizing coverage in wireless sensor networks. J. Ambient. Intell. Humaniz. Comput. **11**(10), 4177–4194 (2020)
7. Banerjee, A., De, S.K., Majumder, K., et al.: Construction of energy minimized WSN using GA-SAMP-MWPSO and K-mean clustering algorithm with LDCF deployment strategy. J. Supercomput. (2022). https://doi.org/10.1007/s11227-021-04265-7
8. Ye, W., Heidemann, J., Estrin, D.: An energy-efficient MAC protocol for wireless sensor networks. In: Proceedings. Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies, vol. 3, pp. 1567–1576. IEEE (2002)
9. Alvi, A.N., Bouk, S.H., Ahmed, S.H., Yaqub, M.A., Sarkar, M., Song, H.: BEST-MAC: bitmap-assisted efficient and scalable TDMA-based WSN MAC protocol for smart cities. IEEE Access **4**, 312–322 (2016)
10. Rajendran, V., Obraczka, K., Garcia-Luna-Aceves, J.J.: Energy-efficient collision-free medium access control for wireless sensor networks. In: Proceedings of the 1st International Conference on Embedded Networked Sensor Systems, pp. 181–192 (2003)
11. Heinzelman, W.R., Chandrakasan, A., Balakrishnan, H.: Energy-efficient communication protocol for wireless microsensor networks. In: Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, 10-p. IEEE (2000)
12. Biradar, R.V., Sawant, S.R., Mudholkar, R.R., Patil, V.C.: Multihop routing in self-organizing wireless sensor networks. Int. J. Comput. Sci. Issues (IJCSI) **8**(1), 155 (2011)
13. Manjeshwar, A., Agrawal, D.P.: TEEN: a routing protocol for enhanced efficiency in wireless sensor networks. In: IPDPS, vol. 1, no. 2001, p. 189 (2001)
14. Latiff, N.A., Tsimenidis, C.C., Sharif, B.S.: Energy-aware clustering for wireless sensor networks using particle swarm optimization. In: 2007 IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications, pp. 1–5. IEEE (2007)
15. Vimalarani, C., Subramanian, R., Sivanandam, S.N.: An enhanced PSO-based clustering energy optimization algorithm for wireless sensor network. Sci. World J. **2016** (2016)
16. Saha, B., Gupta, G.P.: Improved harmony search based clustering protocol for wireless sensor networks with mobile sink. In: 2017 2nd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), pp. 1909–1913. IEEE (2017)
17. Arjunan, S., Sujatha, P.: Lifetime maximization of wireless sensor network using fuzzy based unequal clustering and ACO based routing hybrid protocol. Appl. Intell. **48**(8), 2229–2246 (2018)
18. Javadpour, A., Adelpour, N., Wang, G., Peng, T.: Combing fuzzy clustering and PSO algorithms to optimize energy consumption in WSN networks. In: 2018 IEEE SmartWorld, Ubiquitous Intelligence & Computing, Advanced & Trusted Computing, Scalable Computing & Communications, Cloud & Big Data Computing, Internet of People, and Smart City Innovation (SmartWorld/SCALCOM/UIC/ATC/CBDCom/IOP/SCI), pp. 1371–1377. IEEE (2018)
19. Krishnan, M., Yun, S., Jung, Y.M.: Enhanced clustering and ACO-based multiple mobile sinks for efficiency improvement of wireless sensor networks. Comput. Netw. **160**, 33–40 (2019)
20. Wang, J., Gao, Y., Liu, W., Sangaiah, A.K., Kim, H.J.: An improved routing schema with special clustering using PSO algorithm for heterogeneous wireless sensor network. Sensors **19**(3), 671 (2019)
21. Vijayalakshmi, K., Anandan, P.: A multi-objective Tabu particle swarm optimization for effective cluster head selection in WSN. Clust. Comput. **22**(5), 12275–12282 (2019)
22. Anand, V., Pandey, S.: New approach of GA-PSO-based clustering and routing in wireless sensor networks. Int. J. Commun. Syst. **33**(16), e4571 (2020)

23. Deepa, O., Suguna, J.: An optimized QoS-based clustering with multipath routing protocol for wireless sensor networks. J. King Saud Univ. Comput. Inf. Sci. **32**(7), 763–774 (2020)
24. Banerjee, A., et al.: Construction of effective wireless sensor network for smart communication using modified ant colony optimization technique. In: Bianchini, M., Piuri, V., Das, S., Shaw, R.N. (eds.) Advanced Computing and Intelligent Technologies. Lecture Notes in Networks and Systems, vol. 218. Springer, Singapore (2022). http://doi.org/10.1007/978-981-16-2164-2_22
25. Dhasian, H.R., Balasubramanian, P.: Survey of data aggregation techniques using soft computing in wireless sensor networks. IET Inf. Secur. **7**(4), 336–342 (2013)
26. Al-Karaki, J.N., Ul-Mustafa, R., Kamal, A.E.: Data aggregation and routing in wireless sensor networks: optimal and heuristic algorithms. Comput. Netw. **53**(7), 945–960 (2009)
27. Shao-liang, P., Shan-shan, L., Yu-xing, P., Pei-dong, Z., Nong, X.: A delay sensitive feedback control data aggregation approach in wireless sensor network. In: Lecture Notes in Computer Science, pp. 393–400 (2007). http://doi.org/10.1007/978-3-540-72590-9_54
28. Lu, Y., Comsa, I.S., Kuonen, P., Hirsbrunner, B.: Probabilistic data aggregation protocol based on ACO-GA hybrid approach in wireless sensor networks. In: 2015 8th IFIP Wireless and Mobile Networking Conference (WMNC), pp. 235–238. IEEE (2015)
29. Yu, B., Li, J., Li, Y.: Distributed data aggregation scheduling in wireless sensor networks. In: IEEE INFOCOM 2009, pp. 2159–2167. IEEE (2009)
30. Xiao, S., Li, B., Yuan, X.: Maximizing precision for energy-efficient data aggregation in wireless sensor networks with lossy links. Ad Hoc Netw. **26**, 103–113 (2015). https://doi.org/10.1016/j.adhoc.2014.11.014
31. De Paz Alberola, R., Pesch, D.: Duty cycle learning algorithm (DCLA) for IEEE 802.15.4 beacon-enabled wireless sensor networks. Ad Hoc Netw. **10**(4), 664–679 (2012). http://doi.org/10.1016/j.adhoc.2011.06.006
32. Sinde, R., Begum, F., Njau, K., Kaijage, S.: Refining network lifetime of wireless sensor network using energy-efficient clustering and DRL-based sleep scheduling. Sensors **20**(5), 1540 (2020)
33. Xu, M., Zhou, J., Lu, Y.: PHGWO: a duty cycle design method for high-density wireless sensor networks. In: 2019 IEEE International Conference of Intelligent Applied Systems on Engineering (ICIASE), pp. 28–31. IEEE (2019)
34. Liu, Y., Xiao, J., Li, C., Qin, H., Zhou, J.: Sensor duty cycle for prolonging network lifetime using quantum clone grey wolf optimization algorithm in industrial wireless sensor networks. J. Sens. **2021** (2021)
35. Subramanian, A.K., Paramasivam, I.: PRIN: a priority-based energy efficient MAC protocol for wireless sensor networks varying the sample inter-arrival time. Wirel. Pers. Commun. **92**(3), 863–881 (2016)
36. Iala, I., Dbibih, I., Zytoune, O.: Adaptive duty-cycle scheme based on a new prediction mechanism for energy optimization over IEEE 802.15. 4 wireless network. Int. J. Intell. Eng. Syst. **11**(5), 105 (2018)
37. Khan, A.A., Jamal, M.S., Siddiqui, S.: Dynamic duty-cycle control for wireless sensor networks using artificial neural network (ANN). In: 2017 International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery (CyberC), pp. 420–424. IEEE (2017)
38. Paul, A., et. al.: A neuro-fuzzy based IDS for internet-integrated WSN. In: Bansal, J.C., Paprzycki, M., Bianchini, M., Das, S. (eds.) Computationally Intelligent Systems and their Applications. Studies in Computational Intelligence, vol. 950. Springer, Singapore (2021). http://doi.org/10.1007/978-981-16-0407-2_6