Multiple Mobile Sinks in Large-Scale Wireless Sensor Networks

Subjects: Telecommunications
Contributor: Abdelbari Ben Yagouta , Bechir Ben Gouissem , Sami Mnasri , Mansoor Alghamdi , Malek Alrashidi , Majed Abdullah Alrowaily , Ibrahim Alkhazi , Rahma Gantassi , Salem Hasnaoui

The involvement of wireless sensor networks in large-scale real-time applications is exponentially growing. These applications can range from hazardous area supervision to military applications. In such critical contexts, the simultaneous improvement of the quality of service and the network lifetime represents a big challenge.

multiple mobile sinks   energy consumption

1. Introduction

WSN (Wireless Sensor Networks) is a special case of Ad hoc networks [1], broadly used in various applications such as environment monitoring, object tracking, military surveillance, traffic control, healthcare, etc. A WSN is a collection of large numbers of sensor nodes (SN) distributed over a geographic area to monitor certain phenomena. Each sensor node is limited in processing capability, wireless bandwidth, battery, and memory capacity. Mostly, it is difficult, even impossible, to recharge or change the battery, making energy consumption a significant constraint of WSNs lifetime [1][2].

WSNs have many advantages, and they are widely used due to their low cost, wireless communication capability, energy efficiency, and scalability, and they are suitable for Real-time monitoring applications.

The SNs can sense, process, and transmit data either via multi-hop transmission or directly to a base station (BS). The BS sends the collected data to a remote-control station through radio networks or satellite connections. WSNs have unique features like autonomy, self-organization, and Ad-hoc infrastructure, which makes them ideal for healthcare, smart cities, and environmental surveillance [2][3].

Since wireless communication requires significantly more power than other tasks, energy conservation is important while designing routing protocols for WSNs. The clustering approach is one of the best techniques for reducing the energy consumption of nodes. Therefore, instead of each node sending its collected data individually, first, sensor nodes organize themselves into clusters, and then an elected cluster head (CH) sends all aggregate data to the sink.

Clustering is used in WSNs for several important reasons, as it offers several benefits that contribute to the efficient and effective operation of these networks, such as:

- Energy Efficiency: As sensor nodes, WSNs are usually powered by batteries with energy resources clustering, which plays a role in evenly distributing energy-intensive tasks like data transmission and aggregation among the nodes. By assigning nodes as Cluster Heads (CHs) for collecting and aggregating data, non-CH nodes can conserve energy and extend the network lifespan by operating in low-power modes for longer periods.

- Reduced Communication Overhead: In clustered WSNs, the sensor nodes within a cluster typically transmit collected data to their respective CH. The CH, then. Forwards the data to the base station or sink node. This approach reduces communication distances within the network since data does not need to be transmitted to the base station. Consequently, reduced communication distances lead to energy consumption and alleviate network congestion.

- Scalability: With clustered WSNs, new nodes can easily join existing clusters as the network expands while CHs efficiently route data towards the Base Station (BS). This allows for network expansion without impacting its performance.

- Load Balancing: Cluster Heads are vital in distributing data collection tasks among sensor nodes within their cluster. This ensures that no single node becomes overwhelmed with the responsibilities of gathering data. This load-balancing technique plays a role in avoiding failures of nodes caused by excessive energy usage. Additionally, clustering enhances the fusion of data, allowing for aggregation at the CH level. As a result, redundant information collected by nodes is minimized, leading to the transmission of precise and concise data to the base station.

- Prolonged Network Lifetime: The combination of reduced energy consumption, efficient communication, and optimized data routing achieved through clustering significantly extends the overall network lifetime.

In large-scale WSNs, coverage is one of the most important QoS metrics, and it refers to how well the SNs in the network can monitor or sense the region of interest. Coverage directly impacts the ability of a WSN to fulfill its intended purpose, which could be environmental monitoring, surveillance, or any other sensitive application. In such a context, the battery replacement of large amounts of nodes is a labor-consuming work. Although the life of WSNs can be prolonged through energy-harvesting (EH) technology, it is necessary to design an energy-efficient routing protocol for energy harvesting, as an important part of nodes would be unavailable in the energy harvesting phase. In this phase, a certain number of unavailable nodes would cause a coverage hole, affecting the WSN's monitoring function of the target environment.

In [4], authors propose an adaptive hierarchical clustering-based routing protocol for EH-WSNs (HCEH-UC) to achieve uninterrupted coverage of the target region through the distributed adjustment of the data transmission. The proposal balances the energy consumption of nodes. Then, a distributed alternation of working modes is proposed to adaptively control the number of nodes in the energy-harvesting mode, which could lead to uninterrupted target coverage. The simulation results show that the proposed HCEH-UC protocol can prolong the maximal lifetime coverage of WSNs compared with the conventional routing protocol and achieve uninterrupted target coverage using energy-harvesting technology.

Despite this, numerous challenges such as Quality of Services (QoS), efficiency of used energy, mobility, and lifetime restrict the use of WSN. The QoS and energy consumption are relevant metrics used to assess the quality of paths in any designed routing protocol in WSNs.

The Quality of Service (QoS) is defined by the International Telecommunication Union regulations (ITU-T Supp. 9 of E.800 Series) [5] as the totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service. Also, the QoE (Quality of Experience) is defined as the degree of delight or annoyance of the user of an application or service [6].

QoS in WSN refers to the ability of the network to provide certain guarantees regarding latency, throughput, packet loss, and reliability for different types of traffic. Since WSNs are typically deployed in harsh environments where resources are limited, providing QoS is a hard task to resolve. However, it is essential to meet the application requirements, such as monitoring critical infrastructure, conserving energy, and collecting data.

QoS is a very challenging subject, one of the big defis is how to guarantee QoS. In [7], a new method for QoE parameters prediction in an overall telecommunication system consisting of users and a telecommunication network, based on QoS indicators' values prediction, are overviewed. The presented results show the advantages of the proposed overall model normalization techniques towards adequate prediction and presentation of QoE in conjunction with QoS in the overall telecommunication systems.

Besides, the small battery energy is a major constraint for WSNs. As these nodes are typically deployed in remote and inaccessible locations, recharging them is not feasible. Therefore, the energy resources of the sensors must be used efficiently to prolong the network's lifespan [8][9]. If the network's topology is not variable and the sink remains fixed, the energy distribution will be increasingly uneven over time. The network's longevity is a crucial evaluation standard used to assess its performance, and it is typically measured by determining the period when the first node dies. Over the years, numerous routing protocols and algorithms have been suggested for energy-efficient WSNs, but many of these works suppose that the sink is static [10][11][12][13]. In routing protocols based on multi-hop communications, nodes close to the sink play a crucial role in transmitting data to other sensors. As a result, their energy resources tend to deplete faster, resulting in the hot spots issue [14].

Routing protocols using clustering help sensors sense and reassemble data from the environment and transmit it to the sink with minimum costs. By grouping nodes, clustering algorithms enhanced the performance of nodes and their ability to send data. In cluster-based routing protocols, even cluster heads (CHs) located far away from the sink are more likely to exhaust their battery reserves than those nearby since the needed hops for sending data increase with the square of the distance [15][16]. Node deaths can disrupt the network topology, reduce sensing coverage, and potentially result in a network partition, isolation of nodes, and loss of data. Additionally, in real-time WSN applications, such as military zone monitoring, enemy surveillance, natural disaster tracking (e.g., seismic activities), and exploration of inaccessible areas, stringent quality-of-service constraints are essential. These constraints include high data reliability, throughput network, low data delivery latency, and high communication efficiency, apart from efficient energy usage.

Clustering technology is crucial in reducing the consumed power by attributing sensors to clusters based on specific rules. The cluster features a set of CHs that act as relay nodes for other members within the group. Clustering simplifies the network topology and mitigates the need for sensor-sink communications. Moreover, CHs can leverage data fusion techniques to eliminate repetitive data, thereby lessening the CHs burden. A prominent example of a routing protocol which uses clustering is the “low-energy adaptive clustering algorithm” (LEACH). However, selecting CH in the LEACH is not optimal, and research work is needed to refine the protocol.

Moreover, mobile WSN (MWSN) is a novel variant of networks used in dynamic and mobile environments due to its capacity for self-configuration. In large WSNs, the network can be logically portioned into sub-networks. Each one has its mobile sink. Using mobile sinks is a highly effective approach for managing the imbalanced energy of WSNs. WSNs supporting mobile sinks typically deploy intelligent vehicles or robots to carry the sink, which can be moved freely around the sensing field. The implementation of mobile sinks was suggested and evaluated to address the imbalanced energy problem in WSNs [17][18][19][20][21][22][23].

Mobile sinks controlling region of interest (RoI) gather information from static sensors in one or multiple hops. A significant advantage of multiple mobile sinks is that they can distribute the communication and computation load across the network, reducing the burden on individual sensor nodes. This can significantly enhance the network lifetime by mitigating the effects of energy depletion in specific nodes. Moreover, multiple mobile sinks can help decrease data collection and transmission latency. By deploying sinks in different parts of the network, the time taken to collect and transmit data from distant nodes can be significantly reduced. However, there are some challenges in deploying mobile and multiple sinks. One such challenge is finding an optimal placement of sinks to cover the entire network efficiently. Also, the synchronization of mobile and multiple sinks can be complex. In conclusion, deploying multiple mobile sinks in a WSN is a promising approach for achieving better efficiency, network lifetime, and data collection, but it requires careful deployment and synchronization to realize its full benefits.

2. Multiple Mobile Sinks in Large-Scale Wireless Sensor Networks

In [24], a scheme for maximizing the longevity of WSNs utilizing a movable sink was suggested to manage the delays in delivering data. Each node has a range of tolerance for delay, within which it does not need to instantly transmit data when it is available. Instead, the node can keep data in storage for a while and transfer it at the appropriate time, i.e., when the mobile sink is at an optimal location to lengthen the network’s useful functioning duration.

Moving sink nodes is among the viable ways used to extend the lifetime of the network. As pointed out in [25], this technique can significantly improve network durability. In [26][27], the authors delve further into using numerous mobile sinks to enhance energy efficiency and network longevity. In another study [28], a joint optimization assessment to optimize the network lifetime using mobile sinks is performed by determining K-optimal trajectories and scheduling of sojourn time per position while abiding by the given constraints by sensors and mobile sinks.

Hence, mobility is a prevalent approach for mitigating hotspots' issues and extending the lifetime of multi-hop WSN routing, as highlighted in [29]. Other studies, such as [30], highlight the impact of using mobile sinks on power usage and longevity by selecting optimal sink node numbers and parking positions. In [31], a network restructuring process is proposed by modifying the adjacent nodes of a sink to optimize the lifetime and balance the power usage among sinks.

By ensuring that the total energy of the sink is below a specific threshold, only a set of selected nodes are connected, which enhances the network lifespan. Research in [32] highlights the benefits of using mobile sinks to prolong network life by randomly deploying nodes in a square area or pre-defined rectangular or hexagonal grids. The hexagonal grid deployment strategy is particularly effective since it maintains coverage and connectivity.

In the previously discussed studies, authors highlight only the issues of energy consumption with multi-hop routing, considering some fixed or mobile sinks to reduce energy and improve network lifetime. However, do not give importance to ever-increasing QoS criteria, especially in real-time constraint applications. Since such routing already suffers from an exhilarating node energy consumption and a huge data delivery delay due to the transfer of data between nodes until reaching the BS in multi-hop traveling.

Recently, there has been a significant interest in the development of cluster-based and power-efficient mobile protocols for routing. One such protocol, the “Energy-efficient Cluster-based Dynamic Routing Algorithm” (ECDRA) [33], involves deploying a mobile sink attached to a sensor that rotates circularly to dynamically change the topology of the network in response to the sink's position. However, LEACH [14] is a well-known hierarchical routing protocol differentiating CHs from normal nodes (ONs). ONs transfer their data to the appropriate CHs, which collectively transmit the data to BS. While LEACH is more effective than classical routing protocols at increasing network lifetime, the random selection of CHs can result in uneven distribution and flow between the BS and the CHs, leading to higher energy consumption.

In [34], a framework that enhances energy efficiency and the QoS for WSN is presented. The introduced hybrid technique utilizes a fitness function that considers key performance indicators like the number of neighbors, the set of sensors for each cluster, and how long each node remains the CH. This fitness is integrated with a probability threshold function to influence the procedure of selecting CHs. Compared to previous homogeneous protocols such as LEACH, the proposed method maintains optimal CH selection more stably throughout network operation. Furthermore, compared with heterogeneous protocols like “Developed Distributive Energy-Efficient Clustering and Enhanced Developed Distributive Energy-Efficient Clustering”, the proposed protocol displays superior performance regarding the WSN lifetime, power usage, and throughput. However, this suggested routing algorithm should offer more privacy and security features. Moreover, to prove its consistency, this paradigm should be tested in a real-world context.

The authors of [35] introduced an evaluation technique to compare the “Secure Mobile Sink Node Location Dynamic Routing Protocol” (SMSNDRP) with another algorithm named “routing protocol with K-means for forming Data Gathered Path” (KM-DGP). The application of these two algorithms was on networks with Mobile Sinks of various sizes. QoS and power usage are used to assess the quality of routes and energy consumption patterns of both routing protocols on small (with single and multiple mobile Sinks) and large networks. The proposed evaluation technique is implemented on NS3 using five different scenarios. The findings suggest that compared with KM-DGP, SMSNDRP shows improved network energy consumption on small, single networks. In contrast, for larger networks with sixteen mobile Sink nodes or more, KM-DGP displays comparatively better network energy consumption than SMSNDRP with four mobile sink nodes.

The study in [36] introduces a new high-performance communication protocol for routing packets using multiple mobile nodes. The protocol relies on four main features: assessment of packet delays, independent control of link quality and choosing active neighbors of the nodes. Simulation studies on this protocol show that the latter improves the packet forwarding rates, reduces power usage, and shortens average delays.

The authors in [37] presented a clustering paradigm for MWSN. Their technique involves introducing super cluster heads (SCH) that are static and efficient sensors within the MWSN to gather CH data from CHs. Combining SCHs with the “Minimum Transmission Energy” (MTE) protocol reduces the distance required to transfer data from CH to BS, ultimately improving energy efficiency. Under this approach, data is first transmitted from CH to SCH and then forwarded to BS. This new technique promises to enhance the network performance further.

Another study in [38] introduces a new energy-efficient routing system that employs clustering and sink mobility techniques. The authors propose a two-step approach that involves classifying the region of interest (RoI) into sectors and selecting a CH for each sector based on the weight of each node member. Afterwards, each member calculates the power usage of numerous routing paths and selects the most energy-efficient option. Finally, CHs are linked in a chain via a greedy strategy for inter-cluster connectivity. The findings show, as demonstrated through simulations that this new routing strategy is better than similar approaches, like “Cluster-Chain Mobile Agent Routing” (CCMAR) and “Energy-efficient Cluster-based Dynamic Routing Algorithm” (ECDRA).

According to a recent study [39], an auto-schedule routing algorithm relying on IoT connections was introduced to enhance the power usage of Software-defined networking (SDN) controlled embedded networks. The algorithm starts by constructing the “Neighbor Distance Discovery Protocol”, which identifies the “minimum depletion path” by locating the closest node to the BS. Next, the algorithm executes the “Multipath Cooperative Self-Scheduling Protocol” to establish a non-traffic route. Additionally, the algorithm involves the routing communications of each IoT object in building the routing medium. It computes the average packet loss rate, node response rate, energy consumption, sensor absorption rate, and transmission delay. Finally, the algorithm employs the “Lifetime Duty Cycled Energy Efficient Protocol” to determine the network threshold latency and energy limits.

The research discussed in [40] explores the latest routing algorithms used in sensor networks and proposes strategies for their development. This study highlights recent advances in the strategy used to reduce the energy required for information transmission. One key concern for IoT, which has gained much attention, is the energy requirements to extend the lifespan of IoT networks. One of the approaches that has gained traction is the design of routing protocols that minimize energy consumption during data transmission.

In recent studies, optimization paradigms have been utilized to address the energy issues in WSNs by means of an energy-efficient multi-objective criterion as follows:

The proposed clustering and optimization-based routing approach in [41] is used to improve the power efficiency and prolong the lifespan. The selection of CH is achieved in parallel with the minimization of power usage, which effectively reduces dead sensor nodes. The use of the “Sailfish optimizer algorithm” for optimal path selection also enhances the energy efficiency of data transmission between CH and BS. However, the study does not consider the node mobility in the proposed approach. In WSNs, nodes can move frequently due to environmental conditions or other factors. Hence, the network’s topology varies, which may affect the performance of routing algorithms. Future research could address this limitation by incorporating mobility models into the proposed approach to improve its adaptability to dynamic network conditions.

Moreover, some studies have attempted to enhance the network power usage and its lifespan via various optimization algorithms such as the PSO algorithm [42], bio-inspired ant colony [43], etc. Another research [44] introduced a hybrid ACO-PSO routing paradigm that employs mobile sinks to reduce overall power usage.

Hence, the research gap can be summarized as follows:

Despite the potential benefits of using multiple mobile sinks in WSNs, research gaps should be addressed in this domain. One of the significant gaps is the establishment of performant and robust routing paradigms for multiple mobile sinks since routing protocols determine the efficiency of WSNs. The challenge of multiple mobile sinks is to design a routing protocol to handle the changing positions of sinks and ensure efficient data delivery. Current routing protocols used for multiple mobile sinks are based on centralized approaches, which can lead to scalability issues and network congestion. Another research gap is related to the synchronization of mobile multiple sinks. When multiple sinks move in the RoI, it can be challenging to ensure that they are synchronized in terms of their locations and data collection schedules. Synchronization is essential to avoid collisions and ensure efficient data collection.

Furthermore, the deployment methodology of multiple mobile sinks is another area where research is needed. Identifying an optimal number of mobile sinks, their placement, and their trajectories requires sophisticated algorithms and optimization techniques. Overall, the research gaps regarding using multiple mobile sinks in WSNs include establishing scalable and high-performance routing protocols, synchronization techniques, and optimal deployment methods that can enable efficient and reliable data collection in large-scale WSNs.

QoS in WSNs has been an interesting research topic in recent years. Many WSN real-time-based applications require the support of QoS. However, the development of sensor networks needs to consider various factors such as fault Tolerance, resource allocation, adaptive routing, data reliability, Real-time communication, scalability, and energy efficiency [45][46].

Addressing these QoS challenges in WSNs often involves a combination of hardware and software solutions, including efficient protocols, energy-efficient algorithms, and adaptive strategies suitable to the specific application requirements. Researchers continue to develop innovative approaches to overcome these challenges and enhance the performance of WSNs in various domains [47][48].

Data aggregation is a method to effectively reduce the data transmission volume and improve network lifetime. However, the data waiting for processing in the queue are subject to an extra delay. In Ref. [47], the authors propose an Adaptive Aggregation Routing (AAR) scheme to avoid this problem by dynamically changing the forwarding node according to the length of the data queue and balancing the aggregating and data-sending load. Simulation results demonstrate that compared with the existing schemes, the proposed scheme reduces the delay by 14.91%, improves the lifetime by 30.91%, and increases energy efficiency by 76.40%.

Coverage is a fundamental QoS metric in WSNs that assesses the ability of the network to adequately monitor a target area. It involves careful node deployment sensing range configuration and may require adaptation strategies to maintain coverage over time. In [48], authors propose an energy-efficient clustering routing protocol based on a high-QoS node deployment with an inter-cluster routing mechanism (EECRP-HQSND-ICRM) in WSNs. The new protocol introduces a node deployment strategy based on twofold coverage. The proposed strategy divides the monitoring area into four small areas centered on the base station (BS), and the CHs are selected in the respective cells to satisfy the uniformity of the CHs distribution. The simulation results show that, compared with the general node deployment strategies, the deployment strategy of the proposed protocol has higher information integrity and validity and lower redundancy.

One of the important challenges is the uncertainty of the service of requests. Recently, intuitionistic fuzzy estimations of the QoS have been proposed, such as in this work [49], where three intuitionistic fuzzy characterizations of virtual service devices are specified: intuitionistic fuzzy traffic estimation, intuitionistic fuzzy flow estimation and intuitionistic fuzzy estimation about probability. Six intuitionistic fuzzy estimations of the uncertainty of comprise service devices are proposed. The proposed uncertainty estimations allow for the definition of new Quality of Service (QoS) indicators. They can determine the quality-of-service compositions across a wide range of service systems.

References

1. Cordeiro, C.D.M.; Agrawal, P. Ad Hoc and Sensor Networks: Theory and Applications; World Scientific Publication: Singapore, 2006; ISBN 981-256-681-3/981-256-682-1.

2. Akyildiz, I.F.; Su, W.; Sankarasubramaniam, Y.; Cayirci, E. Wireless sensor networks: A survey. Comput. Netw. 2002, 38, 393–422.
3. Akkaya, K.; Younis, M. A survey on routing protocols in wireless sensor networks. A survey on routing protocols for wireless sensor networks. Ad. Hoc. Netw. 2005, 3, 325–349.
4. Han, B.; Ran, F.; Li, J.; Yan, L.; Shen, H.; Li, A. A Novel Adaptive Cluster Based Routing Protocol for Energy-Harvesting Wireless Sensor Networks. Sensors 2022, 22, 1564.
5. E.800SerSup9 (10/21) Guidelines on Regulatory Aspects of Quality of Service: Recommendation of the International Tele-communication Union. Available online: https://www.itu.int/rec/T-REC-E.800SerSup9-202110-I (accessed on 20 August 2023).
6. P.10/G.100 (11/17) Vocabulary for Performance, Quality of Service and Quality of Experience: Recommendation of the Inter-national Telecommunication Union. Available online: https://www.itu.int/rec/T-REC-P.10-201711-I/en (accessed on 20 August 2023).
7. Poryazov, S.A.; Saranova, E.T.; Andonov, V.S. Overall Model Normalization towards Adequate Prediction and Presentation of QoE in Overall Telecommunication Systems. In Proceedings of the 2019 14th International Conference on Advanced Technologies, Systems and Services in Tele-communications (TELSIKS), Nis, Serbia, 23–25 October 2019; pp. 360–363.
8. Quang, P.T.A.; Kim, D.-S. Enhancing Real-Time Delivery of Gradient Routing for Industrial Wireless Sensor Networks. IEEE Trans. Ind. Informatics 2012, 8, 61–68.
9. Lindsey, S.; Raghavendra, C.; Sivalingam, K.M. Data gathering algorithms in sensor networks using energy metrics. IEEE Trans. Parallel Distrib. Syst. 2002, 13, 924–935.
10. Chen, G.; Li, C.; Ye, M.; Wu, J. An unequal cluster-based routing protocol in wireless sensor networks. Wirel. Networks 2009, 15, 193–207.
11. Wei, D.; Jin, Y.; Vural, S.; Moessner, K.; Tafazolli, R. An Energy-Efficient Clustering Solution for Wireless Sensor Networks. IEEE Trans. Wirel. Commun. 2011, 10, 3973–3983.
12. Jumira, O.; Wolhuter, R.; Zeadally, S. Energy-efficient beaconless geographic routing in energy harvested wireless sensor networks. Concurr. Comput. Pract. Exp. 2013, 25, 58–84.
13. Yahya, B.; Ben-Othman, J. Energy efficient and QoS aware medium access control for wireless sensor networks. Concurr. Comput. Pract. Exp. 2010, 22, 1252–1266.
14. Heinzelman, W.R.; Chandrakasan, A.; Balakishnan, H. Energy-Efficient Communication Protocol For Wireless Micro-Sensor Networks. In Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, Maui, HI, USA, 7 January 2000.
15. Yagouta, A.B.; Gouissem, B.B. Quality of Service and Energy Efficient Evaluation of Hierarchical and Flat Routing Protocols for Wireless Sensor Networks. In Proceedings of the 10th International

Conference on Sensor Technologies and Applications (SENSORCOMM 2016), Nice, France, 24–28 July 2016.

16. Yagouta, A.B.; Gouissem, B.B. Compromises Between Quality of Service Metrics and Energy Consumption of Hierarchical and Flat Routing Protocols for Wireless Sensors Network. Sens. Transducers 2016, 206, 15.
17. Vincze, Z.; Vida, R. Multi-hop Wireless Sensor Networks with Mobile Sink. In Proceedings of the 2005 ACM Conference on Emerging Network Experiment and Technology, Toulouse, France, 24–27 October 2005; pp. 302–303.
18. Akkaya, K.; Younis, M.; Bangad, M. Sink Repositioning for Enhanced Performance in Wireless Sensor Networks. Elsevier Comput. Netw. J. 2005, 49, 512–534.
19. Mnasri, S.; Alrashidi, M. Energy-efficient IoT routing based on a new optimizer. Simul. Model. Pract. Theory 2022, 119, 102591.
20. Chatzigiannakis, I.; Kinalis, A.; Nikoletseas, S. Sink Mobility Protocols for Data Collection in Wireless Sensor Networks. In Proceedings of the International Workshop on Mobility Management and Wireless Access, MobiWac ’06, Terromolinos, Spain, 2 October 2006; pp. 52–59.
21. Yagouta, A.B.; Jabberi, M.; Gouissem, B.B. Impact of Sink Mobility on Quality of Service Performance and Energy Consumption in Wireless Sensor Network with Cluster Based Routing Protocols. In Proceedings of the IEEE/ACS 14th International Conference on Computer Systems and Applications, (AICSSA2017), Hammamet, Tunisia, 30 October–3 November 2017.
22. Hassanat, A.B.; Alkafaween, E.A.; Al-Nawaiseh, N.A.; Abbadi, M.A.; Alkasassbeh, M.; Alhasanat, M.B. Enhancing Genetic Algorithms using Multi Mutations: Experimental Results on the Travelling Salesman Problem. Int. J. Comput. Sci. Inf. Secur. 2016, 14, 785.
23. Yagouta, A.B.; Gantassi, R.; Gouissem, B.B. Compromises between Energy Consumption and Quality of Service Metrics in Wireless Sensor Networks with Mobile Sink and Cluster based Routing Protocols. In Proceedings of the 2017 International Conference on Internet of Things, Embedded Systems and Communication (IINTEC 2107), Gafsa, Tunisia, 20–22 October 2017.
24. Yun, Y.; Xia, Y. Maximizing the Lifetime of Wireless Sensor Networks with Mobile Sink in Delay-Tolerant Applications. IEEE Trans. Mob. Comput. 2010, 9, 1308–1318.
25. Silva, R.; Silva, J.S.; Boavida, F. Mobility in wireless sensor networks—Survey and proposal. Comput. Commun. 2014, 52, 1–20.
26. Shrivastava, P.; Pokle, S.B. A multiple sink repositioning technique to improve the energy efficiency of wireless sensor networks. In Proceedings of the 15th International Conference on Advanced Computing Technologies (ICACT ’13), Rajampet, India, 21–22 September 2013; p. 1.

27. Lee, E.; Park, S.; Yu, F.; Kim, S.-H. Exploiting mobility for efficient data dissemination in wireless sensor networks. J. Commun. Networks 2009, 11, 337–349.

28. Liang, W.; Luo, J. Network Lifetime Maximization in Sensor Networks With Multiple Mobile Sinks. In Proceedings of the IEEE 36th Conference on Local, Computer Networks, Bonn, Germany, 4–7 October 2011; pp. 350–357.

29. Wang, J.; Zuo, L.; Shen, J.; Li, B.; Lee, S. Multiple mobile sink-based routing algorithm for data dissemination in wireless sensor networks. Concurr. Comput. Pract. Exp. 2015, 27, 2656–2667.

30. Wang, J.; Li, B.; Xia, F.; Kim, C.-S.; Kim, J.-U. An Energy Efficient Distance-Aware Routing Algorithm with Multiple Mobile Sinks for Wireless Sensor Networks. Sensors 2014, 14, 15163–15181.

31. Jain, T.K.; Saini, D.S.; Bhooshan, S.V. Lifetime Optimization of a Multiple Sink Wireless Sensor Network through Energy Balancing. J. Sensors 2015, 2015, 1–6.

32. Anand, V.; Agrawal, D.; Tirkey, P.; Pandey, S. An energy efficient approach to extend network lifetime of wireless sensor networks. Procedia Comput. Sci. 2016, 92, 425–430.

33. Wang, J.; Cao, J.; Ji, S.; Park, J.H. Energy-efficient cluster-based dynamic routes adjustment approach for wireless sensor networks with mobile sinks. J. Supercomput. 2017, 73, 3277–3290.

34. Singh, P.; Singh, R. Energy-Efficient QoS-Aware Intelligent Hybrid Clustered Routing Protocol for Wireless Sensor Networks. J. Sens. 2019, 2019, 8691878.

35. Shiltagh, N.A.; Abdullah, M.Z.; Zarzoor, A.R. Evaluation of routing protocol with multi-mobile sinks in WSNs using QoS and energy consumption parameters. Int. J. Electr. Comput. Eng. 2019, 9, 2880–2892.

36. Li, Y.P.; Li, Y.; Wang, Y. High Performance Multi-Mobile Node Routing Communication Protocol based on Reliable Active Node. In Proceedings of the 2020 6th International Symposium on System and Software Reliability (ISSSR), Chengdu, China, 24–25 October 2020; pp. 104–108.

37. Kadiravan, G.; Sariga, A.; Sujatha, P. A Novel Energy Efficient Clustering Technique for Mobile Wireless Sensor Networks. In Proceedings of the 2019 IEEE International Conference on System, Computation, Automation and Networking (ICSCAN), Pondicherry, India, 29–30 March 2019; pp. 1–6.

38. Wang, J.; Gao, Y.; Liu, W.; Sangaiah, A.K.; Kim, H.-J. Energy Efficient Routing Algorithm with Mobile Sink Support for Wireless Sensor Networks. Sensors 2019, 19, 1494.

39. Dhandapani, A.; Venkateswari, P.; Sivakumar, T.; Ramesh, C.; Vanitha, P. Cooperative self-scheduling routing protocol based IOT communication for improving life time duty cycled energy efficient protocol in SDN controlled embedded network. Meas. Sensors 2022, 24, 100475.

40. Kaur, L.; Kaur, R. A survey on energy efficient routing techniques in WSNs focusing IoT applications and enhancing fog computing paradigm. Glob. Transit. Proc. 2021, 2, 520–529.
41. Mehta, D.; Saxena, S. MCH-EOR: Multi-objective Cluster Head Based Energy-aware Optimized Routing algorithm in Wireless Sensor Networks. Sustain. Comput. Inform. Syst. 2020, 28, 100406.
42. 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 2019, 19, 671.
43. Wang, J.; Cao, J.; Sherratt, R.S.; Park, J.H. An improved ant colony optimization-based approach with mobile sink for wireless sensor networks. J. Supercomput. 2018, 74, 6633–6645.
44. Gao, Y.; Wang, J.; Wu, W.; Sangaiah, A.K.; Lim, S. A Hybrid Method for Mobile Agent Moving Trajectory Scheduling using ACO and PSO in WSNs. Sensors 2019, 19, 575.
45. Pundir, M.; Sandhu, J.K. A Systematic Review of Quality of Service in Wireless Sensor Networks using Machine Learning: Recent Trend and Future Vision. J. Netw. Comput. Appl. 2021, 188, 103084.
46. Osamy, W.; Khedr, A.M.; Salim, A.; El-Sawy, A.A.; Alreshoodi, M.; Alsukayti, I. Recent Advances and Future Prospects of Using AI Solutions for Security, Fault Tolerance, and QoS Challenges in WSNs. Electronics 2022, 11, 4122.
47. Li, X.; Liu, A.; Xie, M.; Xiong, N.N.; Zeng, Z.; Cai, Z. Adaptive Aggregation Routing to Reduce Delay for Multi-Layer Wireless Sensor Networks. Sensors 2018, 18, 1216.
48. Xu, K.; Zhao, Z.; Luo, Y.; Hui, G.; Hu, L. An Energy-Efficient Clustering Routing Protocol Based on a High-QoS Node Deployment with an Inter-Cluster Routing Mechanism in WSNs. Sensors 2019, 19, 2752.
49. Poryazov, S.; Andonov, V.; Saranova, E.; Atanassov, K. Two Approaches to the Traffic Quality Intuitionistic Fuzzy Estimation of Service Compositions. Mathematics 2022, 10, 4439.