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Routing in Wireless Sensor Networks Using Optimization Techniques: A Survey

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Abstract
Over the past few decades, one of the important advancements in wireless communication is low cost and limited power devices known as wireless sensor networks (WSNs). Sensor nodes are used to transmit data but have limited amount of energy. As the transmission takes place, energy gets depleted. So energy consumption and network lifetime are the major challenges in a WSN. Much research has been done in the past years to determine an optimal path between source and destination nodes, which will result in maximizing energy conservation of a network. However, the challenge is to create a routing algorithm that takes into consideration the major issues of minimizing energy consumption and maximizing network lifetime. Various optimization techniques are available to determine a routing path between a source node and destination node. In this article, we look into the details of routing in WSN using different optimization techniques. This article provides us a comprehensive summary of the previous studies in field of WSN during the span of 2010–2019. The results provided in this article provide the future insight for researchers to fill in existing gaps in the WSN research field and to find new research trends in this area.

Keywords Optimization techniques · Routing in WSN · Wireless sensor network (WSN)

1 Introduction

Over the past decade, Ad hoc Network (MANET) has become one of the important technologies in the field of microelectromechanical (MEMs) systems. It has many potential applications such as in military, science, engineering, health care, environment and earthquake prediction. For example, a doctor can remotely access and monitor patient's information using sensor nodes. Ad hoc networks are categorized into two types: Mobile Ad hoc Network (MANET) and Wireless Sensor networks (WSNs). MANET

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consists of moving or static mobile devices that are not embedded in one location, while in a WSN, nodes are deployed in some geographical region that helps in monitoring and sensing required information. Both networks are similar, i.e. both are distributed networks, battery operated, uses multi-hop routing protocol, etc. However, sensor nodes in WSN are cheap as compared to nodes in a MANET network. WSN nodes require little or no maintenance costs once deployed as a network. The basic goals of a WSN are:

- Monitor any specific or target area,
- Detect and record the occurrence of events, and
- Measure the required parameters.

WSN can also detect foreign agents or chemical substances present in the air or water. WSN consists of a network of sensor nodes that are deployed randomly in a large target area. These tiny devices have sensing units to sense required information, process it and send it to the destination which is a Base Station (BS) or the sink [1]. Each sensor node consists of three subsystems: communication, sensing and processing subsystems. A communication subsystem has a transceiver embedded in it to exchange sensed information with external systems. Each Sensing subsystem has transducers in it to collect information about the environment. A processing subsystem has an embedded processor to process local sensed information. The processed data is sent by the transmitter to a base station (BS). Some sensor nodes have two additional units for location finding and for moving the sensor nodes so that they can carry out the tasks assigned to them. Sensors are deployed in such a manner that they have limited resources like energy, power and communication capabilities. Initially every sensor has limited amount of energy but as the transmission takes place, energy gets depleted. It is not always feasible to replace or recharge sensor nodes because the target area is usually unattended. In this case, if a single node dies, the network may become non-functional. So, energy consumption and prolonging network lifetime are major challenging tasks in a WSN. Routing in WSN is an active research problem and researchers are finding ways for improving the performance of a WSN. Up till now, energy efficient routing is a major challenge to be addressed. For efficient communication to take place, a routing protocol is needed between sensor nodes (routers) of a WSN to specify a route between a source node and a destination node. Routing protocols will set up paths for the communication to take place between sensor nodes and the sink. These routing paths are expected to optimize the network lifetime. Many protocols for energy efficient routing are designed to distribute the load among all sensor nodes, thus reduces the power consumption in a WSN.

Routing protocols can be classified as flat and hierarchical routing protocol. In flat-based routing protocol each sensor node is at the same level and having unique global address while in hierarchical approach such as LEACH, C-LEACH and TBC, some form of hierarchy is utilized. Routing is one of the hardest problems for which we cannot use deterministic algorithm. So, optimization algorithms are used to present low cost paths among different number of paths. By implementing swarm intelligence (SI) based algorithms, various routing algorithms have been developed. SI can be considered as an analogy between computing methods and nature inspired behavior of the swarm. These swarm based intelligent algorithms have the potential to achieve optimal solutions for real world problems. The most popular SI based optimization techniques for routing algorithms include Ant Colony Optimization (ACO), Particle swarm Optimization (PSO), Firefly algorithm (FA), Artificial Bee Colony (ABC), and Bacterial Foraging Optimization (BFO).

In this article, we present an up-to-date survey regarding these techniques and compare them to determine which techniques are more appropriate in terms of energy consumption and network lifetime. In this article, we also talk about various challenges in routing of WSN and identify ways to address these challenges using optimization techniques. The main aim of this article is to study the current state-of-the-art optimization techniques used in routing data via WSN and identify efficient approaches for routing in a WSN. The rest of the article is organized as follows:

In Sect. 2, some of the existing related work regarding this topic is discussed, while all background information and optimization techniques fall under Sect. 3. Section 4 explains the methodology used to conduct this survey, while Sect. 5 presents some of the results of research questions mentioned in Sect. 4. Section 6 provides contribution and future directions of this survey article and in the end, Sect. 6 concludes this work.

2 Related Work

Much work has been done in the field of WSNs from the last decade [2–4]. They all use traditional routing protocols for WSN. Some recent research surveys on routing of WSN using optimization techniques are presented in this section.

Zengin et al. [5] conducted a survey on routing protocols for WSNs. In this article, different routing protocols are discussed to deal with the problems of scalability, battery life, adaptability, complexity and survivability. According to this survey, ant-based approach is regarded as a good approach and has attracted many researchers than any other schemes.

Saleem et al. [6] conducted a survey on Swarm intelligent based routing protocol in WSNs and various design issues and protocol taxonomies are discussed. The aim is to identify effective optimization algorithm as they show the same trend for scalability, additivity and robustness as natural system of inspiration. They also provide some details regarding swarm intelligent algorithms and its possible implementation for routing in a WSN. A list of essential features is identified to point out the issues present in its evaluation process and include this in implementing any future real-world applications.

Zungeru et al. [7] conducted a survey by comparing Swarm based routing protocols with classical routing protocol. Routing protocols are categorized as data centric, hierarchical, location based and quality of service (QOS). Different routing protocols are re-simulated using MATLAB based simulator to see the results and provide a benchmark for future work.

Ali et al. [8] conducted a survey on MANETs and WSNs based on swarm intelligence. They identify that the Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) provide more promising results in case of loop free, energy aware, multi-path routing. The parameters used to evaluate the performance of these protocols include route overhead, route optimality, and energy consumption. This article includes critical analysis of all techniques for ad-hoc and wireless networks and concludes that PSO and ACO outperform the other routing techniques.

Guo et al. [9] conducted a survey of intelligent routing protocols in a WSN with an aim of optimizing network lifetime. They discussed intelligent algorithms such as Reinforcement learning (RL), Genetic Algorithm (GA), Fuzzy Logic (FL), and Neural Networks (NNs), to analyze their performances in terms of the network lifetime.

Saleh et al. [10] presented a recent survey on routing with an aim of optimizing energy consumption. This provides a comprehensive survey of energy aware protocols in a WSN.

It also provides a summary of important attributes that are used in different schemes. Different routing protocols that fall under ACO scheme are considered and their limitations and strengths have been pointed out.

Gui et al. [11] conducted a survey on swarm intelligence-based routing protocols for WSN. By first presenting the properties of swarm intelligent algorithms, they identify routing protocols to have a new optimization technique. They discuss some of the properties of termite colony optimization and spider monkey optimization. They also consider issues present in this approach and indicate future directions.

Parwekar et al. [12] provides study of optimization techniques for WSN. They identify some of the hard problems like clustering, node localization and routing, which cannot be addressed using deterministic approach; therefore, optimization algorithms are more suitable for them. They provide critical analysis of all optimization techniques and use this for future directions.

This study on routing in WSN helps in differentiating between various optimization techniques as well as providing comprehensive insight on different challenges such as: energy consumption, network lifetime, and packet delivery ratio, etc. This survey is different from other older surveys as our focus is to provide up-to-date survey in this topic and compare different optimization techniques so we can explore new approaches to address existing problems of routing in a WSN. We review most of the optimization techniques present and try to determine shortcomings and challenges in routing of WSNs. We first provide an overview on WSNs, some of its challenges, definition of optimization and then routing techniques, which is our main concern in this article. This study will provide the reader with adequate knowledge about WSN and optimization techniques for routing in WSNs. Moreover, in order to carry out a systematic review, more than 100 papers are reviewed published in the span of 9 years from 2010 to 2019.

The developed statistics assists in finding shortcomings present in different techniques and indicate ways to fill existing gaps in the area of routing in WSN. Hopefully this study will aid readers to explore more about new approaches in future to identify research in routing in WSNs.

3 Background

Wireless Sensor Network (WSN) refers to a network of hundreds and thousands of sensor nodes densely deployed at a large target area to monitor and record various physical conditions such as temperature, wind, pressure, humidity and many more at various locations. Sensor nodes are battery operated and can access the remote location where human access is limited or not possible. WSN system, consisting of a data acquisition module for collecting data and forwarding module for transferring data to sink node using some routing protocol. Sink node is connected to internet via transceiver stations. Figure 1 illustrates a typical WSN. Red lines in the figure demonstrate the transmission route from sensor nodes to the sink. Information collected at the sink node is then transmitted to the internet.

When compared with traditional wireless network, every sensor node is initially preloaded with limited amount of energy and the battery can't be easily replaced [13]. But, as the transmission takes place, the energy gets depleted. Thus, energy is consumed by the network in information transmission and that's why energy consumption is a major challenge in a WSN. Hence, route optimization techniques play an important role in a WSN, as optimal routing will result in less energy consumption and thus improving the

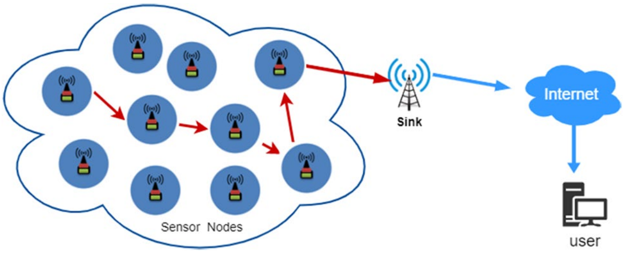

Fig. 1 Structure of a WSN

network lifetime [14]. Route optimization algorithms not only consider path length but are concerned about saving energy and maximizing network lifetime. Traditional route optimization methods are based on Dynamic Programming (DP) which uses Dijkstra and Floyd-Warshall [15] to find an optimal path. These tradition routing techniques are good in obtaining optimal solutions, but their computational power consumption is very large. Another reason is that dynamic programming is difficult to link with complex routing problem. Previous researches have shown that Swarm intelligent algorithms and Genetic algorithm, are useful for optimal routing in a WSN. However, these techniques offer advantages as well as disadvantages. Thus, it is important to find out the techniques with maximum advantages. Route optimization in a WSN is multi-objective optimization problem. The objective of route optimization techniques is to find energy efficient and reliable route for transmission to take place from sensor nodes to the sink. The aim of this survey is to compare different optimization techniques and identify a technique that consumes less energy and maximizes network lifetime. For this, we first need to investigate various routing challenges in WSN.

3.1 Routing Challenges in Wireless Sensor Networks

1. *Energy consumption* is a major challenge in a WSN. If the path from the sensor node to sink node is not the best, more energy is consumed by the network.
2. *Load balancing* is another challenge in a WSN, which may occur due to uneven distribution of sensor nodes. Sensing and transmission loads are ought to be distributed uniformly between nodes of every cluster for a uniform power consumption to take place.
3. *Node deployment* is another challenge that occurs due to random or manual deployment of sensor nodes in a WSN. In random deployment of nodes, routing path must be discovered for energy efficient connectivity and network operation.
4. *Data gathering* is an important step in WSN as in some cases, similar data from multiple nodes may be aggregated that eliminate redundant and correlated data. This type of data aggregation should be encouraged as it results in reduction in the number of transmissions.
5. *Latency* refers to an end-to end delay in data packet delivery. This is another challenge in WSN as multi-hop and data aggregation in some cases, can minimize delay in data transmission.
6. *Scalability* is another issue in WSN as many sensor nodes are present in a network. So, routing algorithm must be capable of coping with scalable network.

7. *Fault tolerant* refers to the capability of nodes to face node failure. For example, in case if any sensor node fails due to power loss, damage or any other reason, sensor nodes should be capable of determining another best path for transmission.

Routing is an energy consuming technique, which is itself a major challenge in WSNs. Routing refers to finding the best possible path from a source sensor node to the BS. If path from source node to BS or sink is not the best, that path will not be followed by other nodes as more energy is consumed. So, special care should be taken while designing routing protocol for WSN. Some of the above-mentioned problems are NP-hard problems, meaning that they cannot be solved using a deterministic approach. To address this kind of problem we need some optimization or high-level procedure or algorithm. Optimization technique uses some objective function to find the best and optimal solution.

3.2 Optimization

Optimization is the process used to address NP-hard problems. NP-hard problems cannot be solved using deterministic approaches within a specific time. Optimization techniques use objective function, which can be maximized or minimized depending upon the problem. This optimization technique can also be referred to as metaheuristic optimization as we use some high level or metaheuristic procedures. Objective function of Optimization techniques can be either single-objective function or multi-objective functions. All points converge to a single point in single-objective function and that single point is the optimal solution. When particles converge at two or more points, that means there are two or more optimal solutions. But, the best one among them is selected in case of multi-objective function. Some of the optimization algorithms uses local search in its operation while some techniques use global search for finding the best solution. To find the best solution among different solutions, some approaches uses local search to refine single solution, which is exploitation oriented, while the other one is population based that explores global search for its operation. Some of the single solution-based techniques are: Tabu search and simulated annealing. Population based techniques are of two types: Evolutionary based and Swarm intelligence. Evolutionary based approaches include Genetic Algorithm (GA) and Differential evolution. While swarm intelligence includes Ant colony Optimization (ACO), Particle Swarm Optimization (PSO), Artificial bee colony (ABC), Firefly Algorithm (FA), and Bacterial foraging optimization (BFO).

3.2.1 Need of Optimization

Optimization is needed to create a well functional design as per the requirements. Network optimization is needed for achieving desired goal that minimizes energy consumption or maximizes the network lifetime. In a WSN, energy consumption, network lifetime, security, and packet delivery ratio are some of the major challenges in routing.

4 Routing in WSN Using Different OPTIMIZATION Techniques

The subject matter reviewed in this article is based on systematic literature review in routing of WSN using Optimization techniques. We searched for the works regarding this topic and classify them into different optimization techniques. Most of these papers are related to routing problem while some of the research papers are related to clustering and routing. All these papers talk about optimization techniques used to solve WSN problems, viz., improve network lifetime, minimize energy consumption and increase throughput.

4.1 Search Strategy

Search strategy used in this study is explained as follows. Research questions, topic related terms, short phrases with Boolean operators (ANDs and ORs) are used to limit our search. We use search terms such as: "Routing via WSN using Optimization techniques", "Optimization techniques used in routing of WSN", and "Wireless Sensor Networks and Optimization techniques for routing ". Different digital libraries were used to search for research papers like Google Scholar, Science Direct, Research Gate, Springer, IEEE Explorer and Science Hub. Using these libraries, almost 114 publications were used in this survey.

4.2 Papers Filtering

Initially 229 papers were obtained using previously explained research strategies. Paper filtering is done to select only relevant papers and results are discussed in every chosen article. We remove all duplicated papers obtained from different libraries. Then, we apply exclusion/inclusion criteria to include only relevant papers. Then, we examine previous survey papers. We include only those papers that are related to routing in WSN using optimization techniques and exclude all those papers which are not covering this topic.

4.3 Classification of Papers

Different types of research papers are reviewed in this study which includes survey papers, conference papers, journals and workshops. Some papers are also publications of research institutes. Each of these focuses on minimizing energy consumption and prolonging lifetime of the network. We reviewed these different papers to answer our research questions. Table 1 represents distribution of works studied. Majority of them are journal papers, about 66% are identified as journal papers while about 32% of papers are conference papers. Distribution scheme of papers can be clearly seen in Fig. 2.

4.4 Classification of Optimization Techniques in the Area of Routing in WSN

Among the 105 examined papers, different optimization techniques have been identified including Genetic algorithm, Ant colony Optimization, Particle Swarm Optimization, Bee Colony Optimization, and Bacterial foraging optimization. Their classification is shown in Fig. 3.

Table 1 Distribution of papers considered

Types of papers	No. of counts	Percentage
Conference	34	31.77
Journals	71	66.35
Review articles	2	1.86

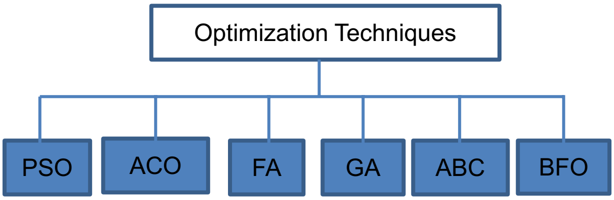

Fig. 2 Percentage of papers in each type

We reviewed all of these techniques and classify them as shown in Table 2 and compared them with each other to show their pros and cons. These optimization techniques are compared and analyzed to observe their feasibility in routing and gain insight. Various papers used different techniques for optimizing their results.

Next, an explanation of each of these techniques along with their background information that related to routing in WSN and all recent work in each of these techniques is elaborated as follows.

4.4.1 Particle Swarm Optimization (PSO)

Particle Swarm is a nature inspired optimization technique that was first introduced by Eberhart and Kennedy [16]. This technique mimics the social behavior of birds flocking in which there is no head or a leader such as animal flocks. They randomly find their food, which is nearest to the food position. Animals always move in the form of a group specially birds and fishes and they never collide with each other. This is due to the reason that every member of the group follows their group leader and adjusts its position and velocity accordingly. Thus, this would also reduce the effort to search the food. Animals also inform each other about the position and location of food. In particle swarm optimization technique, 'bird' is represented by a single solution and sometimes it is also called as particle. Every particle has its fitness value associated with it to evaluate the quality of solution.

Two-tier Particle Swarm Optimization (PSO) routing protocol is developed. Using PSO, clustering and routing problems are addressed. This will improve energy efficiency, cluster quality and network coverage by optimally selecting CH from sensor nodes while routing algorithm uses particle encoding scheme and fitness value to find the best path from these CH to the Base station [17]. In another paper, authors address two issues of clustering and routing using PSO approach [18]. The routing scheme is implemented using PSO with multi-objective fitness function. Linear/Nonlinear programming (LP/NLP) formulations are used in this approach which improves the network lifetime, delivery ratio, energy

Fig. 3 Classification of optimization techniques

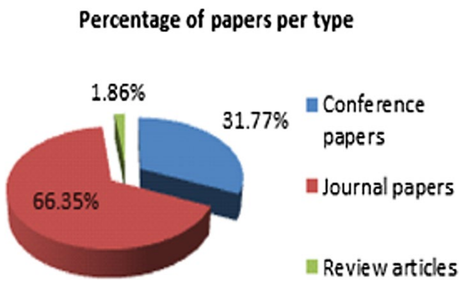

Table 2 Summary of comparison of different optimization techniques

Attributes	ACO	GA	PSO	FA	ABC	BFO
Search parameter	In search of food, ants find the shortest path	In search of parents to form good trait offspring	In search of food, birds find the optimal path	Attraction of fireflies on basis of flashlight	In search of food, honeybees find the path	In search of nutrients, bacteria move and finds shortest path
Operators	Pheromone concentration	Chromosomes in the form of ‘0’ and ‘1’	Particle position and velocity	Firefly attraction w.r.t. distance	Nectar amount	Amount of chemotaxis
Optimization/advantages	Useful for finding near optimal solution or fast convergence and reliable path for transmission	Useful for searching optimal solution. Good algorithm for selection of required sensor nodes	Useful for searching optimal solution and fast convergence. In terms of energy consumption, it shows better results as compared to ACO	Useful in multi-objective optimization problems	Useful for slow convergence problems	Used to solve optimization problems having good energy consumption as compare to PSO and ABC
Clustering and routing	Used to find shortest optimal path and transmission is better as compared to others	This technique has predefined number of clusters reducing communication distance	CH is selected based on high energy node and finds optimal path	Select nodes in the cluster based on distance for optimal routing	CH is selected based on intra-cluster communication distance	Grid base clustering is done for optimal routing
Limitations/weakness	It consumes more energy for number of paths, so energy optimization is a major challenge of a network. Not as good as PSO in terms of energy consumption	Mobile sensor nodes are difficult to manage	Works best if used with other techniques. The average number of hops is larger in this for multi-hop communication. Increased network overhead	This algorithm has high computational cost. Delayed link establishment, delayed route discovery and delayed data transfer	Slow in case of data forwarding. Network lifetime and energy consumption is average as compared to others	For large geographical area its performance is not good in terms of network lifetime

consumption and dead sensor nodes. One routing protocol of optimized energy efficient routing protocol (OEERP) is proposed in [19]. This approach improves network lifetime by uniformly draining sensor nodes energy. This approach has no beacon-based transmission to reach the access point. One drawback of this approach is that residual nodes are created in clustering phase, which affects system lifetime as compare to other approaches. In [20], the authors proposed Enhanced optimized energy efficient routing protocol (E-OEERP), which avoids the chances to form individual/residual nodes in clustering that improve the system lifetime. Particle swarm optimization (PSO) and Gravitational search algorithm (GSA) are used for clustering and finding the route from CH to BS or to the next hop in route construction phase. In [21], Saranraj and Selvamani proposed new technique by combining Ant colony with PSO to form Particle with Ant Swarm optimization for stable clusters with optimal cluster head selection in a WSN. In this approach, pheromone guidance of ant colony is applied locally to the PSO for synchronizing the position of particles to attain the best fitness value and find the best route from a CH to the BS. This improves the network performance and energy consumption.

In [22], the authors proposed an algorithm that combines PSO with neural networks to make a system scalable to enable the addition of some extra nodes in the WSN. The work makes a system secured and easily scalable. WSN with fixed sink node often suffers from hotspot problem as they have more traffic burden near the sink node. So, transmission process is delayed. To improve this, the authors of [23] presented a PSO energy efficient algorithm for mobile sink nodes with some controlling parameters that improves transmission delay and prolongs network lifetime. A novel Particle Swarm Optimization Routing (PSOR) protocol has been proposed in [24] to find optimized path that consumes less energy in transmitting data. In this protocol, energy is used as a fitness function to determine the optimized path among many routing paths. This protocol shows better results as compared to genetic algorithms.

After evaluating all these papers, we can say that PSO is an efficient algorithm and shows improvement in energy consumption and has quick convergence. Multi-hop communication is not as good for PSO.

4.4.2 Ant Colony Optimization (ACO)

Ant Colony Optimization is another nature inspired algorithm that was first introduced by Marco Darigo and Gambardella [25]. This approach helps finding an optimal and reliable route from a source to its destination, which is food in case of ACO. This technique mimics the way real ants try to search their food. Initially, they move randomly in search of food. When Ants move, they leave pheromone ('marker') liquid, which evaporates as time passes. These pheromones indicate the ants' route and that path is followed by other ants having maximum pheromone concentration. This technique is used to find near optimal solution and shortest path for transmission in a WSN.

In [26], Liu presented an optimal distance based transmission strategy (ODTS) along with ACO. This strategy is useful as shortest distance between nodes can be determined. It consumes less energy, hence, increases network lifetime. A new amended ACO is presented in [27] for efficient and reliable routing. In this approach, intelligent ants are present having some information regarding other nodes. This amended ACO technique works better as compared to ACO. In another paper [28], the authors proposed a new ACO based routing algorithm in which pheromone updated operator has been implemented for reducing energy consumption and this scheme would equally divide dissipated energy among all sensor nodes. This approach reduces the overall energy consumption of the network and enhances lifetime of the network.

In [29], adaptive clustering-based routing protocol using ACO is introduced. Generalized ACO is used for optimal setting of data aggregation and route selection. Energy efficiency was further improved by maintaining a balance between energy consumption and efficient routing. In [30], fuzzy logic system is proposed to evaluate node's local information and determine whether a node should become a cluster head. Then, min max adaptive ACO is applied for routing from a cluster head to the BS. This approach improves the energy consumption and reduces the chances of being a hotspot. Another meta-heuristic ACO is used in WSN to minimize energy consumption. This approach uses the concept of Rendezvous node and estimates the Haversine distance to reduce the message transmission dimensionality [31].

In a survey paper [32], different shortest path finding techniques, which use ACO, are presented. Instead of selecting the next node for transmission, nodes in the shortest path are chained together to improve the energy factor of the network. In [33], clustering and routing challenges are addressed by using ACO to solve the issue that includes an energy factor in its probability, which creates an equilibrium in the energy consumption of nodes and improves the network lifetime.

ACO is helpful in finding shortest optimal path for reliable routing and provides fast convergence. The main drawback includes more energy consumption as compared to PSO.

4.4.3 Firefly Algorithm (FA)

Firefly algorithm (FA) is a new optimization technique first proposed by Dr. Xin She [34]. This technique mimics the way real flies get attracted to each other based on flashlight. The pattern, which is produced by the flash of fireflies, is unique and depends on the species. Fireflies have two basic functions of attraction, mating patterns and preys. Female firefly will reply to the male with some unique flashing patterns in mating function. The distance between fireflies is inversely proportional to the light emitted by fireflies. This means attraction between fireflies is only based on brightness. Light intensity will decrease if the distance between two fireflies increases. The same behavior is implemented in firefly algorithm where randomly generated solutions are represented as fireflies and brightness is linked with the performance of the fitness function.

For routing in WSN, firefly algorithm uses residual energy, node distance, and energy as its fitness function to identify route from CH to its BS [35]. This algorithm provides better performance as compared to existing ones and is very useful for CH selection. In [36], firefly algorithm is implemented and compared with PSO by decreasing fitness function as hop count increases. This is useful for routing in WSN by conserving energy of nodes and adding residual energy in its fitness value. In [37], energy efficient routing algorithm is proposed using ACO and firefly algorithm. Both algorithms are compared in terms of performance and it showed that FA performs better as compared to ACO for short routes. ACO works better for long routes with good speed.

Another technique has been proposed by [38], where one special mobile sink node is introduced, named as mobile data transporter (MDT) that collects data from every sensor node by visiting all of them and then forwards the data to the BS. Then firefly algorithm is implemented to simulate this technique. The approach minimizes the path length as compared to that of an ACO. Another evolutionary discrete version of Firefly algorithm (EDFA) is presented in [39] to solve vehicle routing problem with time windows

(VRPTW). A novel route optimization operator is implemented for minimizing the number of routes present in a network.

Firefly algorithm is helpful in case of multi-objective optimization problems. Data transmission and delayed route discovery are the main drawbacks of this technique.

4.4.4 Genetic Algorithm (GA)

The genetic algorithm (GA) is one of the optimization techniques inspired from the Darwinian theory of biological evolution, reproduction and "survival of the fittest". GA was first proposed by Holland et al. [40]. It mimics the way genes are transferred from parents to offspring via selection, crossover and mutation operators. In selection phase, some of the individuals are selected for crossover and mutation; genes are exchanged in crossover to produce offspring whereas new traits are added in mutation phase. The same behavior is implemented in Genetic Algorithm in which population is represented as chromosomes and each string of chromosome is represented in the form of binary or real numbers. Initially, population is generated randomly, and the next generation of population is generated using these three fundamental mechanisms of selection, crossover and mutation [41]. The objective function will evaluate the quality of chromosome produced in a population. Genetic algorithm is used to solve search and optimization problems.

In [42], GA is used for optimizing the distances between nodes so that they can drain less energy. The objective function includes transmission distance of all sensor nodes to the CH and from the CH to the BS. In this approach, a CH is selected having maximum residual energy and is used to reduce the distance between the CH and the BS. The use of GA, reduces the transmission distance and thus improves the network lifetime. An improved genetic algorithm is developed in [43] by reducing/eliminating the possibility of selecting invalid node for routing, thereby improving the system performance.

In [44], clustering and routing problems are addressed together using Genetic Algorithm (GA) that improves the energy consumption and the network lifetime. Another approach presented in [45], combines genetic algorithm with simulated annealing to construct energy efficient paths. Instead of random deployment, the approach considers sub-optimal energy dissipation of individual nodes to improve the network lifetime. Another genetic algorithm-based routing scheme called GAR has been proposed in [46] that minimizes total distance travelled and quickly computes the new routing schedule based on current network state. This approach works better as compared to others in terms of total distance covered and the network lifetime.

In [47], different techniques and hybrid approaches using GA are presented to compare energy consumption of each technique. In [48], GA is applied to routing protocols for WSN. In this approach, spanning tree topology is implemented for WSN that enhances network lifetime. Long distance communications are one of the reasons of large energy consumption. Thus, [49] proposed hierarchical based clustering using genetic algorithm to improve network lifetime. In [50], energy efficient algorithm based on GA is proposed to prolong the network lifetime and that reduce total communication distance.

GA is helpful to solve all kinds of optimization problems. For selecting some specific sensor nodes, GA is helpful. The main drawback of this technique is that we cannot use this technique for moving and mobile sensor nodes.

4.4.5 Artificial Bee Colony (ABC)

Artificial Bee Colony (ABC) is a meta-heuristic algorithm inspired from intelligent foraging behavior of honeybees. This technique was first proposed by Karaboga [51] that mimics the way bees move in search for food. Artificial bees have colonies which consist of three groups of Onlookers, Scout and employed. Employed bee has a job to search for food or food source position. When employed, a bee needs to communicate with other bees or share the information by dancing with nectar amount after finding the food source. The onlooker bee is waiting in the dancing area for the food. The duration of their dancing depends on the nectar amount. A good nectar amount will attract more bees to come and that path is followed by many other bees. The same behavior is implemented in Artificial Bee Colony (ABC) algorithm. Employed bee randomly search for solutions, while solution quality depends on the nectar amount, i.e., fitness value.

In [52], an energy efficient algorithm is proposed for WSN using ABC algorithm. In this approach, clustering and routing algorithms used the ABC technique. This approach shows better performance in terms of the network lifetime and packet delivery ratio.

In [53], power efficient cluster-based routing algorithm is presented using ABC called as (ABC-SD). Low power clusters are formed, and routing problem is addressed using cost-based function using energy efficiency and the number of hops in a path. This approach shows good performance in terms of the network lifetime, packet delivery ratio and the network convergence.

ABC is helpful for slow convergence and can easily be used with other techniques. Its energy consumption needs further improvement as is not as good as compared to other approaches.

4.4.6 Bacterial Foraging Optimization (BFO)

Bacterial Foraging Optimization (BFO) belongs to the field of Swarm Optimization, which is inspired by foraging group of bacteria. This technique was first proposed by Passino [54]. This technique mimics the way bacteria move in search of nutrients. Bacterium in search of nutrients will take small steps in the environment and this process is known as Chemotaxis. The same behavior is implemented in Bacterial Foraging Optimization technique in which bacterium represents solution and the amount of nutrients indicates the fitness value.

In [55], clustering and routing problems are addressed using BFO algorithm. This approach includes residual energy and the distance in the fitness value, which is used to optimize the network lifetime and improve the energy consumption. In [56], grid-based routing algorithm using BFO approach is used in which grid wise clustering is performed. Routing is done using BFO by considering energy and distance in fitness function to extend the network lifetime that makes stability period longer.

Another approach presented in [57] for mobile sensing in WSN is proposed, where data gathering is done using drones and BFO is used for routing. Energy consumption and network lifetime is improved using this approach.

BFO is useful for optimization and having good energy consumption value as compared to PSO and ABC.

5 Discussion and Future Directions

There are other studies that adapt optimization techniques and related to routing in WSN. In [58], Particle Swarm Optimization is used to select optimal clusters using transmission distance and residual energy. PSO is used to solve p-center location problem [59]. In [60], minimizing the distance in network using PSO are used to solve location problem. Network lifetime can be maximized using an improved PSO approach in which transmission distance, relay node, and energy efficiency are used to remove excess energy of a system [61].

In [62], Tabu PSO is used to select optimal routing path, which results in improving efficiency of the system. Another Tabu search based routing algorithm (TSRA) is proposed in [63], which results in more balanced transmission among nodes and improves both the energy consumption and the cost of routing. In [64], a hybrid approach is used for energy optimization problem using PSO. All these papers use PSO algorithm as an optimization approach.

In [65–74] they all use Ant colony optimization in routing of WSNs. In [75], Firefly algorithm is used to find unknown nodes with optimal solution. These class of papers [76–79] belong to Genetic Algorithm. In [80], Beehive Optimization (BHO) approach is used to increase the lifetime of a network. In [81] Bacterial Foraging Optimization (BFO) is used to improve network lifetime and throughput. In [53, 82, 83, 84, 85] some of the energy efficient routing protocols are discussed.

We also reviewed some of the survey papers to answer our research questions mentioned in methodology section. In different survey papers [79, 86–109] use different parameters for energy consumption in a network. In ACO-based clustering and routing algorithms, CH is selected periodically as sensor nodes act as an ant while routing path serve as ants foraging. Sensor nodes dynamically compute probability value to select an optimal path among several paths to prolong network lifetime. To solve energy problem, traditionally two kinds of pheromones are used in ACO. One local pheromone and another global pheromone are used. Another modified version of ACO has been implemented having multiple pheromones and this technique is known as MPACO. This approach makes economical use of the node energy as this considers distance between sensing nodes, residual energy and the number of neighboring nodes. This technique shows 20% more lifespan as compared to traditional ACO and 300% more lifespan as compared to other fuzzy techniques. This approach has scalability issue which can be improved as a future approach. According to the approach presented in [71], PSO shows better results as compared to ACO in terms of energy consumption and network lifetime. Limitations of this approach include minimizing energy consumption of the network furthered by using PSO with other techniques. Another drawback of this technique is that we have a larger number of hops present between CH and the destination and transmission rate is reduced in multi-hop communication.

Genetic algorithms have been used for optimal routing and useful for selection of active sensor nodes present in a WSN. This improves the network lifetime. But genetic algorithms are not useful to handle mobile sensor nodes. On the other hand, BFO is known to perform better as compared to PSO and ABC in terms of network lifetime if geographical area is not too large.

From the findings of our previous discussions and based on Table 3, which shows a summary of contributions of previous studies for each class of such techniques, we derive the conclusions as summarized below:

Table 3 Summary of contributions of previous studies for different optimization techniques

Optimization technique	References	Task of optimization technique	Performance metrics	Tools used	Network
PSO	[17]	Solves CH selection problem Finds the optimal routing Tree that connects the elected CHs to the BS.	Scalability, PacketDeliveryRate (PDR) at the CHs and delivery of total data packets to the BS	OMNeT ++ platform	Homogenous and heterogeneous
	[18]	PSO-based routing algorithm with a trade-off between transmission distance and number of data forwards with efficient Particle encoding scheme and multi-objective fitness function PSO-based clustering algorithm with efficient particle encoding Scheme and fitness function	Network life, energy consumption, dead sensor nodes and Delivery of total data packets to the base station	MATLABR2012b and C programming language	Homogenous
	[20]	Effective cluster formation takes place using Particle swarm optimization in order to reduce the individual/residual node formation	Total energy consumption Throughput Packet delivery ratio Overall network lifetime	NS-2.32 simulator	Homogenous
	[22]	Utilize PSO learning algorithm to train the weights of feed forward neural network	Average energy consumption Average control packet overhead Packet delivery ratio (PDR)	Not specified	Homogenous
	[23]	Uses the PSO algorithm to divide the network into several regions	Average delivery delay Network lifetime Amount of packets delivered	Not specified	Homogenous
	[24]	Using PSO for generating optimum paths	Distance	(NS2)	Homogenous
ACO	[26]	An optimal-distance based transmission strategy is put forward on the basis of ant colony optimization (ACO)	Network lifetime energy usage	Not specified	Homogenous
	[27]	Enhancing the discover of finest route in WSNs from the sources node to the Base Station the optimal route path is found by intelligent ants	Packet delivery ratio Jitter value	(NS2)	Homogenous

Table 3 (continued)

Optimization technique	References	Task of optimization technique	Performance metrics	Tools used	Network
	[28]	Ant colony based routing Algorithm with special parameters in competency function That try to reduce energy consumption of network nodes And also obtains more balanced transmission among the node and prolong the network lifetime	Average energy consumption Network lifetime	Not specified	Homogenous
	[29]	Route discovery, data aggregation and information Loss are modeled as the processes of pheromone diffusion, accumulation and evaporation	Energy consumption and connectivity	Not specified	Homogenous
	[30]	Adaptive max–min ant colony optimization is used to construct energy-aware inter-cluster routing between cluster Heads and base station (BS),	First node died (FND) and half of the nodes Died (HND) Energy consumed	Not specified	Homogenous
	[31]	Prediction of optimal path, novel cluster head selection is achieved using Meta Heuristic Ant colony optimization	Packet delivery ratio (PDR), energy consumption, residual Energy, percentage of nodes dead and number of packets received at BS	NS-2	Homogenous
	[33]	A routing algorithm which is based on the ant's capability of finding the best paths between a food source and their nests	Energy consumption Lifecycle	MATLAB R2014b	Homogenous

Table 3 (continued)

Optimization technique	References	Task of optimization technique	Performance metrics	Tools used	Network
FA	[35]	Firefly algorithm based routing technique which Considers residual energy, distance and node degree in its Fitness function formulation and it provides the complete Routing solution for multi-hope communication between the CH and BS	Residual energy, number of alive nodes and data packet received at BS	Matlab and Java programming	Homogenous
	[36]	Firefly algorithm based approach is proposed for energy efficient routing in WSN	Throughput Network lifetime	ns-2.35	Homogenous
	[37]	The firefly algorithm was modified to handle The discrete problem of route selection	Energy consumption	Not specified	Homogenous
GA	[42]	Finding the optimum number and Location of cluster heads (CHs)	Energy consumption	Not specified	Homogenous
	[43]	Routing optimization in wireless sensor networks	Energy consumption Network lifetime	MATLAB R2010a	Homogenous
	[44]	Clustering and routing in wireless sensor networks	Total distance covered First gateway die Number of hops Dead gateways Dead sensor nodes Energy consumption	MATLABR2012b and C programming language	Homogenous
	[45]	Routing optimization in wireless sensor networks	Dead sensor nodes Lifetime Packet receipt ratio	MATLAB/TOSSIM	Homogenous
	[46]	Compute a new routing schedule based on the current network state	Network life time and energy Consumption	MATLAB (version 7.5)	Homogenous
	[48]	Genetic algorithm is used to recalculate the routing topology of a wireless sensor network	Energy Consumption	TOSSIM	Homogenous

Table 3 (continued)

Optimization technique	References	Task of optimization technique	Performance metrics	Tools used	Network
	[49]	Incorporate genetic algorithm (GA) with hierarchical clustering For the sake of reducing the long-distance communications	Energy Consumption Distance	Not specified	Homogenous
	[50]	GA for clustering sensor nodes and selection of the minimum of clusters	Energy Consumption Distance	MATLAB	Homogenous
ABC	[52]	Clustering and routing in wireless sensor networks	Network lifetime and amount of packets received by the BS.	OMNet++4.6 platform	Homogenous
	[53]	Clustering and routing in wireless sensor networks	Data packets received by the BS Energy Consumption First node die Communication overhead	Castalia 3.2 simulator	Homogenous
BFO	[55]	The CH selection and routing	Residual energy, Number of alive nodes and data packet received at BS	Matlab and Java Programming	Homogenous
	[56]	Routing in wireless sensor networks	Network lifetime	Matlab	Homogenous
	[57]	Proposition of a mobile sensing scheme based on an Approach inspired by the BFOA	Delay, energy consumption, Network coverage and successful amount of collected Data	OMNet++4.6 platform	Homogenous

- Most routing protocols are designed according to the principle of reducing power consumption to improve the WSN lifetime with low power consumption and low overhead costs.
- Most protocols assume nodes have an overall knowledge of the network.
- Termination time, the optimal parameters and convergence time of the optimization techniques were not discussed in depth.
- Scalability and fault tolerant in the existing optimization techniques are not fully explored.
- Most of the previous work ignores the analysis and discussions of message and time complexity of their approaches.
- Moreover, many areas are not fully explored such as cross-layer methods, mobility, data transfers, non-uniform deployment, etc.
- BS mobility is not fully addressed and use of multiple BS is not discussed. WSN Mobility is becoming a prominent area of research, and popular due to its flexibility for deployment in any context and managed with rapid topology changes. However, this area has not been fully explored. New strategies in mobility of WSN should be explored, especially related to the mobile BS and head nodes.
- If the WSN nodes possess distinct attributes and capabilities, then such a WSN is termed to be heterogeneous WSN. Unlike homogeneous networks where all nodes have identical abilities and attributes, heterogeneous WSNs are able to perform better in diverse environments. However, the impact of heterogeneity on routing has not been exploited.
- Most of the previous research papers use performance metrics focused on distance, energy consumption, network lifetime, packet delivery rate and delay. There are many other metrics that should be used to correctly evaluate the proposed protocols such as reliable delivery, load balancing, complexity, scalability, control messages and quality of service.
- Transformation of existing simulations into real-world applications and Cross-layer optimization through optimization techniques are important challenges.

Saleem et al. [6] have mentioned some of the features that must be present in routing algorithm for WSN such as energy efficiency, WSN security, memory requirement, scalability, load balancing, node localization, fault tolerance, and hardware requirements. These features have a direct impact on the design issues of a WSN. It can affect network performance and capabilities. However, a new approach is needed which can cover multipath routing problems, scalable performance, network failure detection, backup, locality of interaction and self-organizing behavior.

Therefore, we are looking at better approaches that can include these features by extending network lifetime and using multiple paths in the network as a backup if the primary path fails. It increases the reliability of a network that should be scalable enough to add as many nodes as we desire. Sensors must coordinate with each other to easily track the target and there should be backup present in case of failure of sensor nodes.

According to our study of various optimization techniques, ACO is regarded as a reliable algorithm for multipath transmission of data that maximizes the network lifetime. ACO shows better performance as compared to other techniques in terms of real time computations. ACO has also some weak points as energy consumption is not as good as PSO. ACO is combined with Breadth First Search to form hybrid approach (ACO-BFS) [110] to find an optimal path in the network as this approach consumes less energy. This technique has better performance as compared to other former ACO techniques in terms of energy consumption. This hybrid approach may not be suitable for large convergence area since a large amount of memory is required. Its computational time is also very high if the CH is far away from the sink.

Therefore, in future we need to use some other technique instead of BFS to manage memory and time requirements. We investigate whether we can combine ACO-BFS with ABC to form a hybrid approach of ABC-ACO. This hybrid approach is observed to work well as ACO-BFS does not work in a large geographical area. So, ABC can compensate to work for large geographical area. Otherwise, we can also use CH not far away from the sink. There exist many CH selection techniques. For this, we should use CH selection including residual energy and distance to the CH as decision parameters. For selection of CH, GP-LEACH and HS-LEACH algorithms [111] are good choices as they reduce the distance and improve performance.

Artificial Bee colony (ABC) is used to optimize multivariable functions. Convergence speed of ABC is very low. Therefore, ACO is combined with ABC to form hybrid approach to have fast convergence. This hybrid approach should be tested in future to examine the results to solve routing problem in a WSN.

In a recent survey [112], the focus is on termites and spider monkey's optimization to solve the routing problems. Termite Colony Optimization (TCO) is basically an approach that mimics the way termite moves. Spider monkey mimics the fission–fusion social behavior of spider monkeys. Spider Monkey Optimization (SMO) is the same as ABC but shows competitive results as compared to PSO and ABC. SMO consist of six phases: Local Leader Phase (LLP), Global Leader Phase (GLP), Local Leader Learning (LLL), Global Leader Learning (GLL), Local Leader Decision (LLD) and Global Leader Decision (GLD). Work has been done in this optimization technique using cluster-based routing algorithm (SMO-C) for discovering optimal path between a source and the destination. By learning from local and global leader, new population is updated using some threshold limits and if the population is not updated using this threshold limit, they use a random initialization. This approach gives better results in terms of availability of multiple paths while time and space complexity can be further improved. Inspired by this approach, energy aware routing protocol can be considered as a future potential work for this approach. (SMO-CR) SMO routing followed by clustering is used to select the best path from multiple paths and instead of random initialization; we can use k-means to improve time complexity of a network. Local and global leader selection is based on residual energy value that maximizes network lifetime.

Another option to improve the performance of a network is scheduling of sensor nodes. In this strategy, only those sensor nodes, which participate in monitoring a target area should be selected. As a result, the number of nodes that transmit data are reduced, which reduces the energy consumption of the network. Therefore, as a future work, a minimum number of nodes is selected using GA selection criteria, which reduces energy consumption and improves the network lifetime.

6 Conclusion

In this article, we provide a detailed and recent statistical analysis of WSNs and optimization techniques used for routing by extracting information from 105 papers published during the span of 9 years from 2010 to 2019. Most of the papers examined are journal papers (66%) and other (32%) are conference papers and majority of them focus on routing problem. In this study, we investigate various challenges of routing in a WSN and various used optimization techniques are reviewed to indicate which technique can do a better job. Despite the existence of ACO, PSO, BFO and many other optimization methods, there may be many open issues and challenges present to provide optimal solution in a WSN. Majority of these techniques are still under further consideration. The results presented in this article could be helpful in future research to explore more on this topic and help in identifying new areas that have not been examined yet. This study will hopefully give the researchers new insight for future to fill the gap in existing studies.

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