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A comprehensive and systematized review of energy-efficient routing protocols in wireless sensor networks

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ABSTRACT
In the past decade, research community has paid a good attention towards energy-efficient data routing in wireless sensor networks (WSNs). WSNs have left an imprint in various areas, but sensor nodes are battery powered having limited lifetime. So, while designing the routing protocols, the prime concern is reducing the energy consumption and elongating the lifetime of the network. In this review, we have done comprehensive review on routing protocols focusing on prolonging the network lifetime. We have proposed different classifications of routing protocols to have the in-depth knowledge about the literature. These are operation based, environment based, objectives based and a combined form of these along with discussed papers. Thereafter, strength and weakness of the papers are found by doing a comparative analysis and further, a feature-based analysis is done as well to get a quick insight about the network models. Subsequently, future directions are discussed. This review article is written with a clear objective, which is to enable the beginners who want to do research on energy efficiency of the WSNs, by equipping them with understanding of different methods of achieving the same objective and grouping them with the similarity of their utility.

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Wireless sensor networks; routing; single path routing; multi-path routing; network lifetime; delay; fault tolerance

1. Introduction

Business Week announced sensor technology as one of the 21 most promising technologies for the twenty-first century in September 1999 [1]. The first wireless sensor network (WSN) had been evolved in the mid-1970s by the admirable efforts of military and defense fields. For the purpose of intrusion detection, WSNs were also utilized during the Vietnam War. But, their establishment had several pitfalls such as limited storage and processing capacity, limited battery and limited bandwidth. But it had been perceived that advancement in wireless technologies and micro electro mechanical system (MEMS) will change the face of world with their usage in diversified fields. And the dawn came, a few advancement in the MEMS technology has urged the need of research in WSNs.

WSN is a composition of hundreds or thousands of sensor nodes. Wireless nodes are deployed in a random or pre-specified manner. After deployment, wireless nodes can be mobile or stationary depending on the application area. WSNs differ from traditional wireless network, i.e. mobile and ad-hoc networks (MANET) in terms number of nodes deployed, changes in the operations, broadcast communication, limited storage and processing capacity, battery and bandwidth, global identification of each node, etc. [2,3]. In a WSN, changes in the physical quantity or environmental changes can be sensed by these nodes and then, they transmit this data towards powerful Base Station (BS) or sink node as shown in Figure 1 (refer [4]) which can be then analyzed for monitoring the area.

WSNs could have been used to avoid some past incidents, for example, mishappening of Mississippi River in Minnesota on August 2 , 2007, could be easily avoided [5]. Unawareness of the poor condition of Interstate 35W highway bridge which collapsed into fast flowing river resulted into the death of many people. Another mishappening in the forests of California on July 2, 2013, could be avoided where life of 19 firefighters could be saved [6]. Now-a-days, many fields have adopted this technology for different kinds of event detection and monitoring. For example, WSNs are used in military areas, industry process control, environmental monitoring, weather monitoring, infrastructure security, forest fire, missile target tracking, civil structure monitoring, remote sensing, thunderstorm, and many more areas [7–9]. Health of different kinds of structures like bridge, tunnel can be monitored and precautions about bad health of them can be detected earlier [10,11]. For instance, in health monitoring applications, dynamic physiological data from human's body can be collected to find different anomalies and he/she can receive an alert before its occurrence and in this way, doctors can take preventive actions to control the adverse situations [12–14]. In military applications, enemy position can be detected. In offices, temperature can be regulated. In forest areas, monitoring of temperature, speed and direction of the air, moisture present in the soil, wetness of the plant leaves can be done which includes video monitoring. Fire detection can also be done using different sensors and an alarm can be raised which is further sent to the central server [10].

As we have discussed earlier in this section, sensor nodes have to route their data to the BS. This responsibility lies with routing protocols, and they confirm that sensed data should be delivered to BS finally. It has been observed that a lot of energy gets consumed in routing. Percentage of energy consumed by the active sensor nodes in various operations had been observed in the literature shown in Figure 2 (refer [6]).

From this figure, it is quite clear that a major portion of energy get spent during communication, i.e. more than 50% [15]. So, the need of hour is that routing should be done in energy-efficient manner to keep the network alive for a longer duration [16–18]. But the selection of the efficient routing protocols is one of the major issues in WSNs. Therefore, the implementation of routing protocols plays

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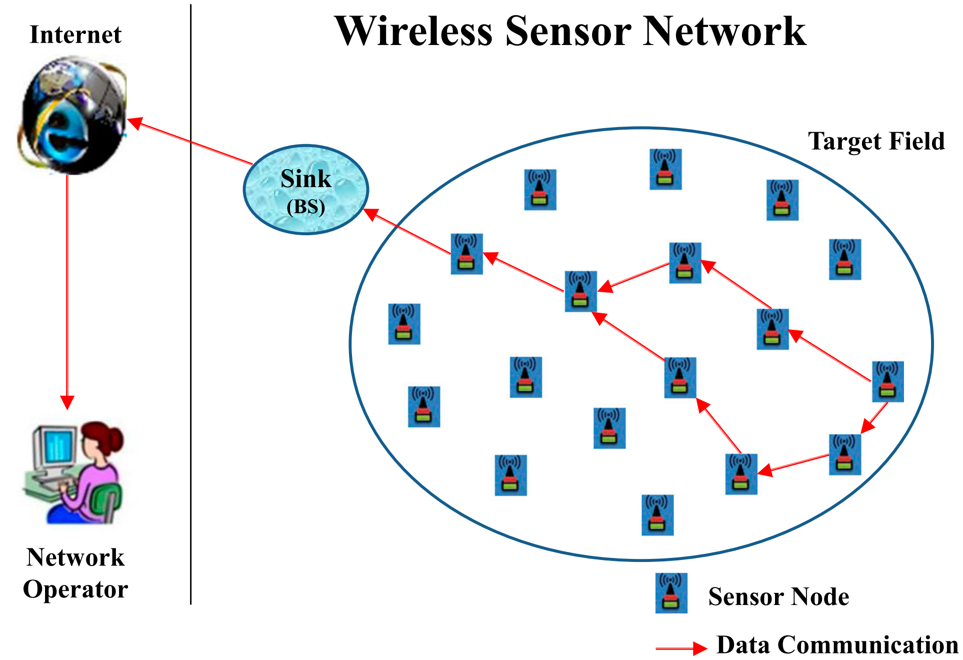

Figure 1. WSN architecture.

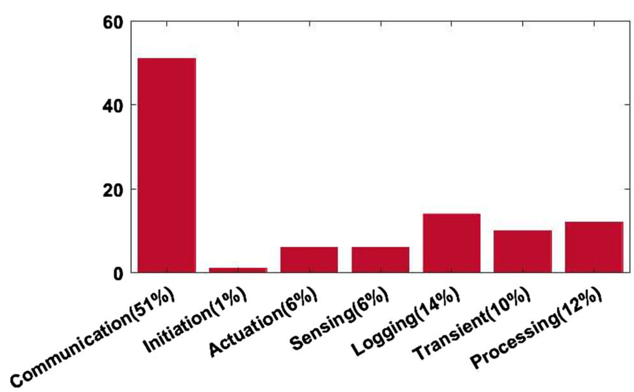

Figure 2. Energy dissipation of a sensor node in various operations.

important role to reduce the energy consumption and elongating the lifetime of the network [4,19,20]. In the literature, Rault et al. have suggested multiple design decisions for energy conservation approaches [21]. These approaches are summarized as follows.

Radio Optimization Approaches: Major components behind the energy dissipation of the sensor nodes are the radio module of the node. Energy dissipation can be minimized by finding optimal modulation metrics or by adjusting the transmission power control or by the formation of virtual transmitter with the integration of various single antenna devices.

Data Reduction Approaches: Amount of data transmitted to the sink can be reduced by applying aggregation or by transmitting the data in the form of linear combinations or using some form of compression techniques.

Sleep/Wakeup Approaches: Energy dissipation can be minimized by utilizing duty cycle mechanisms or inactive wake-up radios or with the control of topology.

Hierarchical Routing Approaches: Energy consumption can be minimized by the usage of clustering. In this, sensor nodes of the network are divided into clusters, and data is routed to the BS through specially selected nodes termed as cluster heads (CHs) by ensuring optimal selection and placement of CHs or with the mobility in the sink node.

Multi-Path Routing Approaches: In this, data packets are transmitted through multiple routes instead of data transmission through single paths. In the literature, these have been termed as single path routing and multi-path routing.

Replenishment of Batteries: Replenishment in the energy can be done through harvesting energy from environment or some wireless charging techniques, etc.

Fault Tolerance Approaches: By re-routing of the data coming through the weaker nodes on time, packet loss and hence, the re-transmissions can be avoided. It can be achieved by maintaining the back-up routes, braided-multi-path routing, etc.

So, we have seen there are so many ways with which energy dissipation can be ameliorated. Now, in the literature, many researchers have proposed a number of routing protocols to achieve various objectives including network lifetime. To measure the effectiveness of these protocols, a number of performance metrics have been used in the literature. Some of widely used metrics are defined next.

1.1. Performance metrics used

In this section, we discuss various performance metrics using which performance of the routing protocols in WSNs is assessed. Advantages of the routing protocols are defined using these metrics.

Packet Delivery Ratio (PDR): It is defined as the number of packets delivered at the BS to the total number of packets generated in the network. PDR defines the efficacy of the network. By using various efficient techniques like load balancing, clustering, multi-path routing PDR can be enhanced.

Network Lifetime: In WSNs, network lifetime of routing protocols is considered as one of the major design objectives. Energy gets dissipated in various operations like sensing, processing and transmitting of the data from the nodes to the BS. Most of the energy is consumed in data transmission. So, for lifetime of the network, number of transmissions should be less. In the literature, network lifetime is defined in many ways such as time till then a particular percentage of PDR is maintained or the death of first node, half number of nodes or the last node.

Stability Factor: In WSNs, due to uneven load, there is an imbalance in the energy consumption of the sensor nodes. In the literature, it is defined as standard deviation in the energy dissipation over all the nodes corresponding to each round. Network lifetime can be enhanced by maintaining the stability factor.

Average Delay: It represents the amount of time required by a packet in reaching from source to destination. Heavy computations on intermediate nodes can be a reason for delay. Path length is also taken into consideration while finding the delay. Path length is defined as the sum of all the path lengths from source to destination divided by number of routes.

In the literature, every year, many papers are coming in this field. In past, researchers have tried to summarize these in different ways in the form of surveys and reviews. In the next section, we are summarizing them.

2. Previous surveys on routing protocols

In this section, we discuss about the reviews and surveys on routing protocols that have been done so far in the literature. Karaki et al. in [22] have discussed about architecture and functioning of sensor network, various routing protocols. Routing protocols are categorized into two classes depending on the network structure and protocol operation. Network structure based protocols are further segregated into flat routing, hierarchical routing, and location-based routing. While protocols operation-based protocols are further segregated into multipath-based, query-based, negotiation-based, QoS-based, and coherent based routing. In their study, authors have discussed about open routing issues and challenges for the realization of sensor network. In [17], a survey of recent routing protocols of WSNs has been done. Also, various design issues related to routing protocols are discussed. In this paper, routing protocols are categorized into three broad types, i.e. data-centric, hierarchical and position based. Further, protocols defined in the literature are classified into these categories. At the end, challenges are discussed.

Tarique et al. in [23] have done a survey on multi-path routing protocols for mobile and ad-hoc networks with the major objective of improving the QoS, reliable communication and minimum overheads. Issues related to the discovery of multiple paths and their maintenance have been presented in a precise manner. A checklist in the form of a guideline is also presented in this paper. In [24], Radi et al. have presented a survey of multi-path routing protocols in which concept behind multi-path routing approach, its basic challenges and enthusiasm behind its usage are explained. A classification of existing routing protocols and their comparative analysis has also been done to provide efficient resource utilization and at the end, research challenges have been discussed. A review of multi-path routing protocols in wireless multimedia sensor network has been done by Jayashree et al. in [25]. Authors have discussed the benefits of multi-path routing. Then a brief discussion about multi-path routing, i.e. path discovery process and related protocols, is discussed. Another survey on multi-path routing protocols in wireless multimedia sensor network has been done by Al-Ariki et al. in [26]. In this survey paper, authors have analyzed the papers on the basis of features those have considered QoS, energy aware routing, geographical routing. A survey on multi-path routing protocols is done by [27] in which Sha et al. have categorized state-of-art work into coding based, infrastructure, non-infrastructure protocols. Infrastructure-based class is further categorized into hierarchical, energy aware and ant-based protocols while non-infrastructure-based protocols is categorized into geography-based protocol. Furthermore, advantages and challenges of multi-path protocols are also studied. For performance analysis, a qualitative comparison between the protocols has been done.

Zin et al. in [28] have done the analysis of requirements pertaining to security and common attacks in WSNs. Thereafter, they have provided the taxonomy of secure multi-path routing algorithms on the basis of how to defend against the common WSNs attacks. Further, investigation about the routing protocols is done through the discussion on their strengths and weakness. Subsequently, comparative analysis is presented based on security infrastructure, security requirements, possible attacks and system efficacy w.r.t. secure data routing in WSNs. A substantial exploration of routing protocols has been done by the research community in recent years. Stavrou et al. have taken security aspect of multi-path routing protocols into consideration in [29]. Various security aspects and need of security in sensitive application areas have been discussed in a very well manner. A threat model is discussed in which various attack strategies, adversary objectives are studied in depth. Furthermore, taxonomy of secure multi-path routing protocol and a trade-off between security and energy-efficiency has been presented. Pantazis et al. have done a survey on energy-efficient routing protocols [30]. In this paper, routing protocols are categorized into four main classes as topology based, communication model based, network structure and reliable routing which are further subclassified into different categories. In this, authors have done an analytical survey of existing energy efficient routing protocols. Moreover, the classification of routing protocols has been extended which is previously defined in [22]. Route selection schemes, communication model and energy consumption model are also discussed.

Then, Rault et al. in [21] have done a survey of energy saving routing protocols by considering specific requirements of the applications. As per the specific requirements, they have categorized the applications and the requirements considered are security, latency, mobility, scalability, etc. It also provides a brief overview of routing protocols which are having a specific WSN architecture. By considering the energy preservation schemes along with requirements, these schemes are categorized into radio optimization, charging, sleep/wake-up schemes and energy-efficient routing, etc. They have classified the requirements and energy efficiency further into three: cross layer, multi-objective optimization and multi-metric protocols. In [31], Sarkar et al. discussed basic architecture of routing protocol as well as a chronology of routing protocols in WSNs. A review of best 50 papers pertaining to energy efficiency, delay, security and reliability has been done. Along with that, routing problems and routing related optimization problems present in these papers have been reviewed chronologically. Analysis of literature work is done on the basis of network configuration, deployment, quality of service (QoS) parameter and experimental setup. Afterwards, research challenges have been discussed briefly. A survey on energy efficient routing protocols and real-life applications of WSNs has been presented by Mohamed et al. [15]. Thereafter, a detailed analytical study showing the strengths and weaknesses of the proactive routing protocols is done as well as network setup and data transmission. Further, a comparison of periodic monitoring applications is done using simulation results. This survey provides the required information needed to start a real-time application. But this survey paper has confined itself to the security.

After going through the literature surveys conducted in past, following points have been observed: (i) many recent surveys and reviews conducted are written either by aiming security, multi-media or applications related. So, we thought to review on energy-efficient routing protocols. (ii) Also, while doing literature surveys on energy efficient routing protocols, researchers have surveyed either single path or multi-path routing based protocols, which could not provide the holistic view to the beginners. (iii) It is also noticed that most of the survey papers have not compared the routing protocols by focusing on the basic methods that are alternate to achieve the same objective across various routing protocols. It helps the beginners in understanding and co-relating the ideas used in the protocols to achieve a particular objective easily.

So, our review paper is written with the objective of helping the beginners who want to do research on energy efficiency of the wireless sensor networks. Also, to present a holistic view to the beginners, single path as well as multi-path routing protocols are discussed. We restricted our scope to the papers published in good journals in the period 2016–2019.

3. Authors contribution and motivation behind

- First, we have proposed two classifications of routing protocols on the basis of operations and the objectives after analyzing the papers based on single path and multi-path routing protocols (see Figure 3 followed by Figure 5). This classification will be really helpful for beginners in saving time and efforts in the sense that quick information can be extracted from the classification that which particular articles have worked on which kind of objectives and in what kind of environment. For a beginner, one of the main tasks is to find out papers having similar kind of environment which further helps him/her while simulating the similar kind protocols having common objectives.
- Second, we have given a summarized tabular representation of single path and multi-path routing protocols in which basic features such as protocol name, methodologies used in the paper to achieve objectives, merits of the protocol, its future work, performance parameters, platform used for simulation, etc., have been considered (refer Tables 2 and 3). This summarized representation can help the beginners in many aspects. For example just by looking over objectives and performance parameters columns, he/she can identify what performance parameters have been used in the literature, to measure the efficacy of a specific objective.
- Third, we have proposed one another taxonomy pertaining to different approaches used to achieve a specific objective, which are utilized by the researchers in their papers discussed in this review article (refer Figure 6). This taxonomy will help the newcomers to identify the alternate approaches that can achieve same objectives.

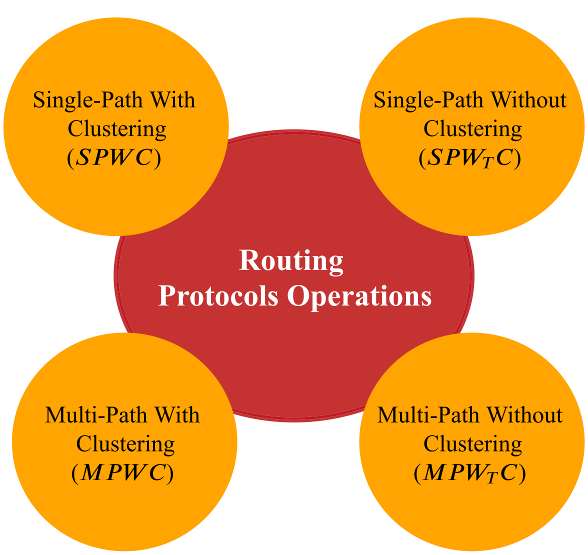

Figure 3. Taxonomy of routing protocols on the basis of network operations and environment.

- Fourth, we have done a detailed comparative study of single path and multi-path routing protocols. We have highlighted their strength and weakness on the basis of the objectives defined in Figure 4, in which authors have contributed. This may help the researchers in finding the research gaps in the discussed paper.
- Fifth, after analyses of the discussed papers, future directions have been given. It will help the researchers to work further.

  To best of our knowledge, above-stated classifications have not been introduced in the past, which give benefits to the beginners directly, thereby reducing their time and efforts to contribute the domain positively. Organization of the whole article is done in this manner: related work is shown by including a summary of the prominent reviews and surveys done in the field of WSNs in Section 2. Classification proposed on the behalf of network operations and environment is discussed in Section 4. In Section 5, classification of routing protocols on the basis of objectives is presented. All the selected papers based on energy efficiency are discussed in brief in Section 6. In Section 7, comparison and analysis on the basis of objectives and features is done. In Section 8, future directions are discussed. Finally, whole of the paper has been concluded in Section 9.

4. Classification of routing protocols on the basis of network operations and environment

Now, continuing from previous discussion, sensor nodes have to route their data to the BS. In routing protocols, the main goal is how to route the sensed data from a node to BS finally. Route information corresponding to each node is kept in their routing table. This information is exchanged among the neighboring nodes. Using this table, next intermediate node is selected. Thereafter, the data packets can be routed through single route only or they can be transmitted through multiple routes. In the literature, these have been termed as single path routing (i.e. SPRP) and multi-path routing (i.e. MPRP) respectively. Now, we will discuss about what are the advantages of these routing protocols, and the issues and challenges related to these in brief.

Advantages of Single Path Routing Protocols

- Single path routing is considered as *simple*. Simplicity of single path routing lies in the fact that routing path between source to destination can be found in fixed time duration and data is routed along one path.
- Additionally, it is considered as *scalable* because the complexity to find the routing path remains as it is, irrespective of the scaling in the network from ten to thousands of nodes.
- Because data is routed through a single path, so *delay* is less in these.

Issues and Challenges of Single Path Routing Protocols

- In single path routing, source node uses the same path repeatedly; this leads to the energy dissipation of intermediate nodes on that path. Due to the use of single path repeatedly without any sharing to other available paths, energy holes problem occurred in network. Hence, it is not considered as energy efficient manner for resource limited WSNs, resulting into shorter network lifetime.
- On the failure of a single node on the path from source to destination, it disrupts the complete flow of data and leads to packet loss in that particular area and re-transmission of sensed data is also not possible. Hence, reliability factor is low, i.e. the amount of data that destination node receives is not equal to the amount of data sent by source node.

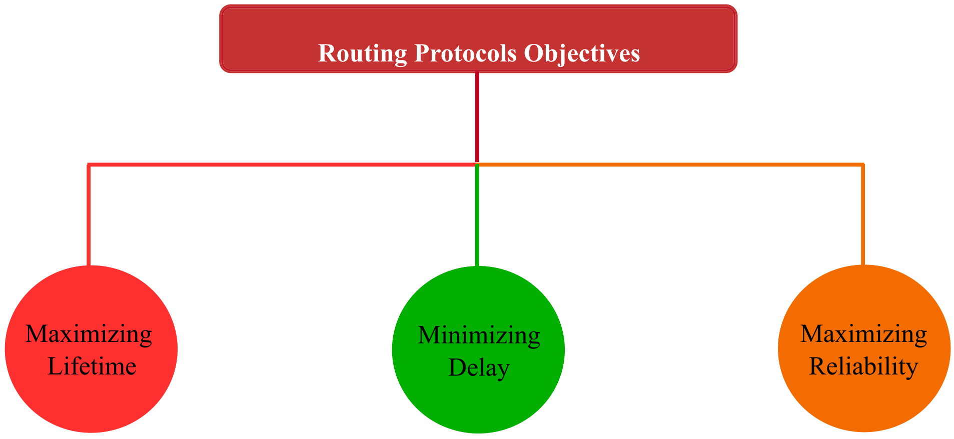

Figure 4. Taxonomy of routing protocols on the basis of objectives.

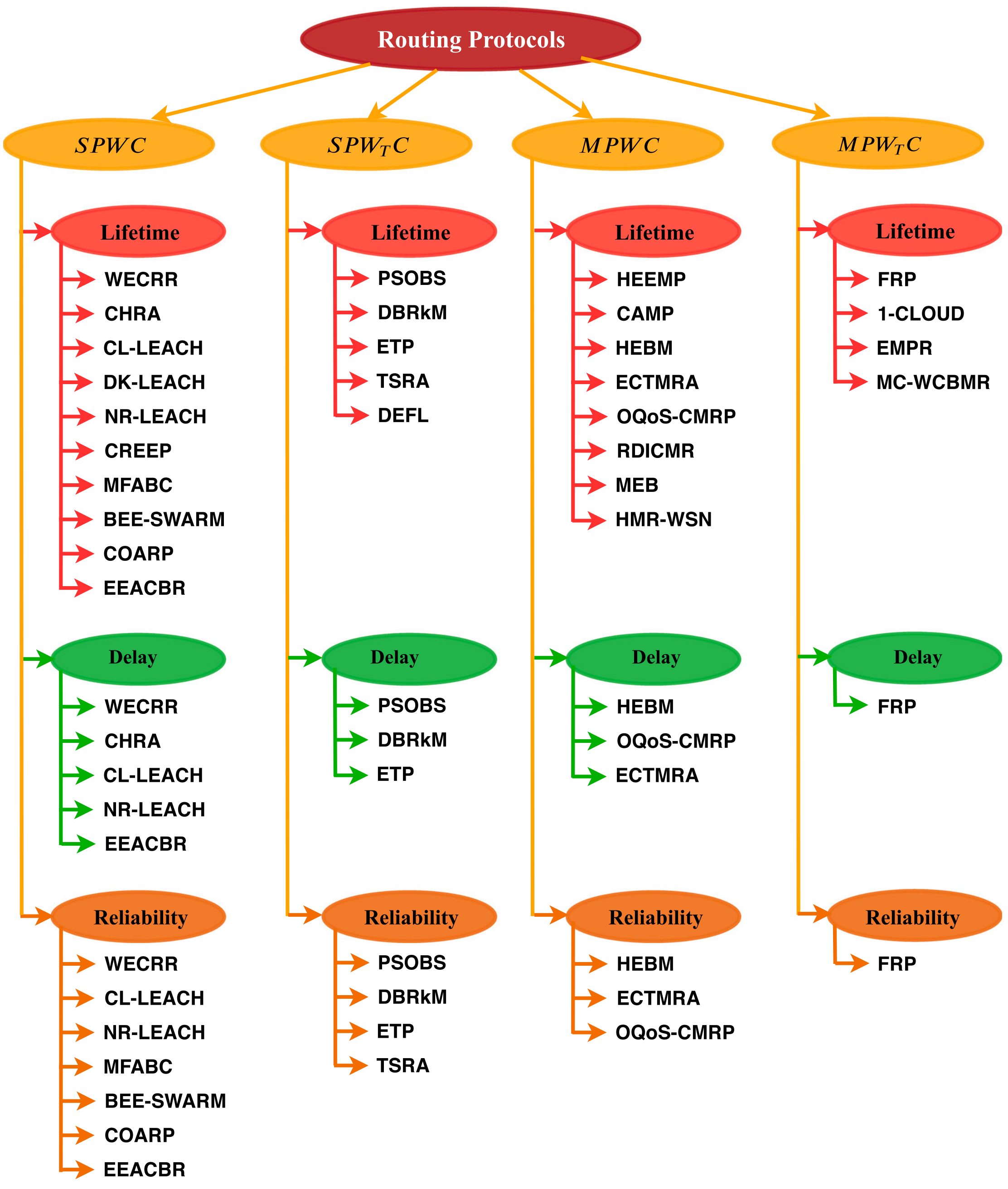

Figure 5. Categorization of papers on the behalf of network operations, environment used and their objectives.

Figure 6. Classification of routing protocols on the basis of objectives and approaches used to achieve particular objectives. This figure summarizes this classification, regarding the papers covered in this review.

- Chances of malicious activities with the data are high as if a single node is compromised, all of the sensed data relayed through that path will be lost. So, single path routing protocols are not secure.

Advantages of Multi-Path Routing Protocols over Single Path Routing Protocols

- In multi-path routing protocols, multiple paths exist between source node and destination, so the energy of single path is not used repeatedly. Probability of occurrence of energy hole problem is very less because the data from source to destination relayed through multiple available paths. It balances the energy consumption throughout the network. Hence, the network lifetime of multi-path routing protocols is generally high. That's why multi-path routing protocols are considered as energy efficient.
- Complete flow of data over multiple links is not disrupted on the failure of single link in multi-path routing protocols. Because data can be transmitted through alternate paths or back-up paths or braided multi-paths, thereby more reliability.
- In multi-path routing, chances of malicious activities are very less because of the presence of multiple paths. However, data in single-path routing protocols will not be safe. Several kinds of attacks like sink hole, selective forwarding, etc. can occur in single-path routing protocols. Additionally, encoding techniques can be applied to prevent eavesdropping. So, multi-path routing is more robust and secure than single path routing protocols.

Issues and Challenges of Multi-Path Routing Protocols

- In multi-path routing protocols, many control packets are exchanged between the nodes in the network to find the optimal routes between source node and destination node. Also, routing over multiple routes results into increased delay.
- Transmitting the data over multiple paths needs to be fragmented using some coding schemes. Though this approach will save a large amount of energy to be depleted, but it requires additional computational overheads at each node. Also, if the number of fragments received is less, then the original data that has been sent cannot be recovered.
- While discovering the multiple paths, source node needs to check that intermediate nodes are not harmful, their remaining energy and received signal strength. Source node will initiate the path construction again if any of the links fails in between which results into transmission of extra control packets.
- Multi-path routing protocols have two features, i.e. reliability and security. If number of paths is not sufficient, at that time, achieving these features is not possible. So, to disseminate the traffic on different paths, there is need to discover the multiple routes which creates extra cost. To ensure the security, coding schemes are used which also creates extra overheads.

For the benefit of the reader, summary of the discussion above is tabulated in Table 1.

Differences between Single Path and Multi-Path Routing Protocols. Difference between the routing protocols based on single and multi-path based routing protocols is described in Table 1.

From the above discussion, a newcomer in the field can easily find out which topology is best suited according to the application area and his/her requirements. Also from the above discussion and differences presented in Table 1, although both SPRP and MPRP help in the data routing in their own ways, but they bear major contrast among them. So, in this review, we have focused on the classifications in such a way that classification at the root must bear major contrast as per the ideas of classification algorithms. Inspired from the literature surveys along with classification algorithms, we have identified the attributes for classification having higher differences towards root of the classification tree. After analyzing these, we have noticed that network operations impact the functionality of WSNs fundamentally giving rise in specific features to great extent and reducing others to low level. By considering all these in mind, we have chosen SPRP and MPRP next to root. Along with this, to make the routing protocols energy efficient, network is generally divided into clustered and non-clustered environment. Clustering was introduced to reduce the number of transmission, exploit the resemblance in the sensed values

Table 1. Differences between single path and multi-path routing.

Performance parameter	Single path routing	Multi-path routing
Routing paths	One	Two or more
Link failure recovery time	Requires more time compared to multi-path	Less time required
Space requirement	Routing table requires less time because information about single path needs to be stored	It requires more space depending on the number of paths
Computational complexity	Less computations are required	Large amount of computations are required
Bandwidth requirement	Low bandwidth is provided	Comparably high
Network lifetime	Network lifetime is less	Lifetime of network is high
Data transmission	Done through single path only	Done through single path as well as multi-path
Throughput	Less	Very much better than single path routing
End-to-End (E2E) delay	Less delay	Higher delay

collected from nearby sensors for aggregation and hence, to reduce the energy consumption, in comparison to non-clustered environment. But clustering also comes with many hurdles [32], we will observe it in comparison section as well. So, by considering routing operations and the environment type, we have finally classified the existing routing protocols into single-path routing with/without clustering ($SPWC/SPW_TC$), and multi-path routing with/without clustering based protocols ($MPWC/MPW_TC$) (see Figure 3) in this review.

Now, all the routing protocols are always designed to achieve some specific objectives. After analyzing all the routing protocols, which have been proposed in the years 2016–2019, we have classified the protocols on the basis of their objectives as well (refer Figure 4).

5. Classification of routing protocols on the basis of objectives

So far, we have discussed various routing protocols suggested in the literature, have classified those protocols on the basis of routing operations and environment. Now, as we discussed earlier, each protocol is designed to achieve certain objectives. So, after analyzing all the papers which we will discuss in this review, we have introduced one more classification of routing protocols, i.e. objectives (see Figure 4). The objectives are: (1) maximizing network lifetime, (2) minimizing delay, (3) maximizing reliability.

Short Description of all objectives is as follows: (1) Maximizing Network Lifetime: One of the main objective of all the works discussed in this review is to maximize the lifetime of the network. Network lifetime is generally defined in terms of first node death (time when first node dies), half node death (time when half of the nodes die), last node death (time of last node death), or in terms packet delivery ratio. There are various ways using which network lifetime can be elongated, we will summarize them at the end of this section. (2) Minimizing Delay: Another objective of many works is to minimize the delay. (3) Maximizing Reliability: One another objective of the few works is to maximizing the reliablity (see Figure 4).

Now the main aim of the discussion in this review is to find out what ideas have been suggested by the researchers to elongate the network lifetime, what are the gaps which still have to be bridged out.

6. Review on energy-efficient routing protocols

After analyzing the papers discussed in this review article, we have made a categorization of them on the behalf of network operations, environment used and the objectives meet by them (see Figure 5).

From this classification, one can easily track which papers have discussed about a specific topology and their objectives. It will benefit the beginners in terms of saving time and efforts in searching relevant articles. Now, in next section, we will discuss about the measurements corresponding to all the objectives that have been achieved by using above-discussed approaches and the other as well.

6.1. Discussion of single path routing protocols

Former techniques based on probabilistic approach suffer from non-uniform load distribution and hence imbalance in energy dissipation and among the CHs. To avoid these problems, Haseeb et al. in [33] proposed a deterministic approach, i.e. Weighted Energy-Efficient Clustering with Robust Routing (WECRR). With minimum communication, a hierarchy of clusters is generated and uncertainties in the selection of cluster heads are avoided by using a deterministic weighted approach. This approach considers the parameters energy, node centrality and distance to the BS. WECRR outperforms in real-life network scenarios especially when energy consumption and data delivery are considered. Also in traditional algorithms, end-to-end route discovery is non-optimized. To find the optimal routes, optimized routing decisions are taken by utilizing multi-facet attributes such as optimal routes in terms of energy efficiency, routes incurring less packet error probability and less congested routes. On finding the energy consumed nodes on primary route due to which link failure occurs, a route maintenance strategy is suggested which results in reducing re-transmissions and route breakages. Route maintenance includes finding energy deficient nodes and routes readjustment. Also, re-clustering is done on demand by using a preset threshold value. Simulation results show that WECRR provides better performance in terms of network lifetime, packet drop ratio, average end-to-end delay, routing normalized load and clustering overheads in comparison to its earlier variants.

To balance the energy dissipation and ameliorate the lifetime of the network in heterogeneous environment, Chunlin et al. introduced a clustering based routing algorithm (CHRA) [34]. In this algorithm, authors proposed a solution of how to minimize the deployment of expensive heterogeneous nodes, i.e. the solution gives an optimal count of heterogeneous sensor nodes in the environment. The problem of optimal placement of the sensor nodes has been considered as NP-hard. Authors have found out the suboptimal solution using mixed integer programming. Mathematical methods such as lagrange relaxation and benders decomposition are used to solve the problem of mix integer programming. In CHRA, first, optimal number of CHs is found out. Then, CHs selection is done using LEACH-C algorithm dynamically as in HRA. In CHRA, the common nodes are divided into two divisions. First kind of nodes transmits their data using heterogeneous nodes while others transmit the data to sink via selected CHs. Analysis results show that proposed algorithm, i.e. CHRA increases the stability period, network lifetime, average delivery delay and reduces the energy consumption. Results show that CHRA requires less number of heterogeneous nodes and CHs compared to HRA.

Table 2. Comparative analysis of single path routing protocols.

Protocol	Objective	Methodology used	Merits	Future work	Performance parameters	Simulator used	Network type
WECRR, 2017	Avoid non-uniform energy consumption	Deterministic clustering with use of Weighted Cost Function, Multi-facet attributes	Efficient and reliable data delivery	Enhancement in network life-time by using heterogeneity WSNs and mobility in sink	End-to-End delay, network lifetime, normalized load	NS-2	Homo-geneous
CHRA, 2017	Energy balancing of heterogeneous WSNs	CHs selection in same way as in LEACH-C, Mixed Integer programming	Enhanced stable period and balanced energy consumption	Addition of multi-sinks with mobility to further prolong the lifetime	Delivery delay, energy consumption	Omnet++	Hetero-geneous
CL-LEACH, 2016	Prolonging network lifetime by reducing energy dissipation	CHs selection by using residual energy and distance, Route maintenance	Enhanced network lifetime comparable to LEACH	Energy optimization using wake-up sleep scheduling algorithm	Number of active nodes, energy dissipation and message cost	NS-2.34	Homo-geneous
DK-LEACH, 2017	Reducing the uneven energy distribution	CHs selection mechanism is similar as in LEACH with Cost function	Better network lifetime	Addition of Heterogeneity and mobility to enhance the network lifetime	Energy consumption, count of alive nodes	Atos-SensorSim	Homo-geneous
NR-LEACH, 2017	Minimizing the energy consumption	CHs selection using weighted approach	Enhanced network lifetime with reduced delay	Enhanced network lifetime through fault tolerance and sink mobility	Average delay, PDR, average energy ratio and number of alive nodes	NS-2	Homo-geneous
CREEP, 2018	Reducing computational complexity for the selection of CHs	CHs selection in similar manner as in DEEC, Threshold and Dual-hop based communication	Complexity reduced due to restricting the number of CHs	Improvement in Reliability, Latency, Scalability	Network lifetime and throughput for static and mobile nodes	MATLAB	Hetero-geneous
MFABC, 2016	Minimizing energy consumption, delay and distance	CHs selection with ABC and Fractional calculus	Maximize the life time of nodes	Addition of fault tolerance and mobility to increase the network lifetime	Number of alive nodes, network lifetime	MATLAB	Homo-geneous
BEE-SWARM, 2017	Energy efficient routing in WSNs	CHs selection using Swarm Intelligence technique, i.e. Artificial Bee Colony	Energy efficient along with scalability	System testing on real test bed with heterogeneous networks	PDR, throughput, average energy consumption	NITSS	Homo-geneous
COARP, 2018	Maximizing lifetime and to achieve the energy balance	CHs selection using Cuckoo Search Optimization in different scenarios	Optimized First node death	Induction of mobility to ensure the coverage, QoS parameters like fault tolerance and reliability	Alive nodes, Energy dissipation, Packet delivery ratio, FND	MATLAB	Homo-geneous
EEACBR, 2018	Balancing the energy consumption	Initial and final CHs selection using Genetic Algorithm and K-means Clustering respectively	Faster clustering process using K-means clustering	Reduction in number of transmissions by adding mobility to BS	Network Lifetime, Throughput, Average residual energy	NS2	Homo-geneous
PSOBS, 2018	To elongate the lifetime of the network	Particle Swarm Optimization, Mobile Sink	Efficient management of network resources	Firefly for better selection of Rendezvous points (RPs)	Energy dissipation, Hop count, RPs and Throughput	MATLAB	Homo-geneous
DBR*k*M, 2016	To minimize the energy consumption	*k*-Means, TSP, Mobile Sink	Improved network lifetime, Less energy consumption	Varying the data generation load and accounting sojourn time as in real time scenarios	Lifetime, Energy consumption, Hop counts, Number of active nodes	MATLAB	Homo-geneous
ETP, 2017	To enhance the network lifetime by balancing the energy consumption	Linear programming problem, Heuristics	Improved Lifetime, Less energy consumption and Reduced delay	Enhanced network lifetime by accounting heterogeneous nodes along with clustering	Event delivery ratio, Energy consumption		Homo-geneous
TSRA, 2016	Reducing the energy consumption and routing cost	Tabu search based routing	Reduced cost of rout-ing and energy consumption	Reduction in energy consump-tion using clustering along with CHs selection using nature-inspired algorithms	Network lifetime, Energy consumption and Routing cost	MATLAB	Homo-geneous
DEFL, 2018	To maintain a trade-off between efficiency and energy balancing	Sequential Quadratic Programming, Fuzzy logic, Bellman Ford Algorithm	Increased network lifetime	End to end delay minimization in multi-hop network along with maximizing network lifetime	Network Lifetime, Normalized Residual Energy	MATLAB	Hetero-geneous

Table 3. Comparative analysis of multi-path routing protocols.

Protocol	Objective	Methodology used	Merits	Future work	Performance parameters	Simulator used	Network type
HEEMP, 2018	Minimizing the energy consumption of the network	Centralized CHs selection using residual energy and node degree into account	Improved lifetime, reduced energy consumption and provides high scalability	Work can be extended to show the trade-off between increased delay and energy minimization	FND, Alive node and total energy consumption, stability factor	MATLAB	Homo-geneous
CAMP, 2018	Uniform energy depletion	Virtual Zones, Sink performs CHs selection process, Intelligent Routing Process	Increased network lifetime, Reduced energy consump-tion, and Improved coverage ratio	Protocol enhancement to handle sink mobility, heterogeneity, security, and reliability	Energy consumption, Alive nodes, Coverage ratio, FND	MATLAB	Homo-geneous
HEBM, 2016	Decreasing the overall network energy consumption, balancing the energy dissipation	Hierarchical Clustering, Sleep/Awake mechanism, Load balancing	Prolonged network lifetime, Improved FND and LND, average data transmission delay	Mobile BS concept to gain further energy saving, BS and CHs can be made more fault tolerant	Average residual energy, Alive nodes, Energy Consumption	NS-2	Homo-geneous
ECTMRA, 2017	To achieve enhanced network lifespan	Clustering using Cuckoo search algorithm, Trust and multipath routing techniques	Improved QoS and network lifetime	Algorithm improvement by adding security, mobility and fault tolerance	Average energy con-sumption and latency rate, lifetime, routing overhead, PDR	NS-2	Homo-geneous
OQoS-CMRP, 2017	Reduces the energy consumption in sink coverage area, to solve energy hole problem	CHs selection using Modified PSO, Route establishment with Single Sink-All Destination algorithm, Round-robin Paths Selection algorithm	Prominent data communica-tion with reasonable energy conservation. It also reduces transmission delay and communication overhead	To make the network fault tolerant, Addition of security and mobility in communication	PDR, Throughput, Average Residual Energy, Network Lifetime, E2E delay	NS-2.35	Hetero-geneous
RDICMR, 2016	To reduce the energy consumption	Event-driven dynamic clustering with CHs selection in same manner as in LEACH with modified threshold, biological immune system	Increased Throughput, Lifetime, Higher remaining energy	Reasonable mobility and energy consumption in WSNs with multiple mobile sinks	Number of packets transmitted, Remaining energy, Lifetime of the network	MATLAB	Homo-geneous
MEB, 2018	To mitigate unbalanced energy usage in clustered WSNs	Transmission power control approach, heuristic algorithm	Improved network lifetime		Alive sensor nodes, Lifetime, Stable Operation Period	MATLAB	Homo-geneous
HMR-WSN, 2017	To improve the low throughput, Quality of Service such as low reliability and fault tolerance	CHs election by nodes using Linear, Saati, and Euclidian normalization, Load Balancing	Improved in terms of energy consumption, the average rate of packet delivery, throughput and accuracy	Improvement in degraded performance in terms of average of route setup time, routing overhead and computational simplicity. Secure and trust-based multipath routing protocol	Energy Consumption, Average Packet loss, Average End to End Delay, Average Route Setup Time, Routing Overhead, Throughput	NS2, TRMSim-WSN, Expert Choice and Grey Relational Analysis tools	Homo-geneous
FRP, 2018	Handling multiple failures with least delay, high throughput and least overhead with regard to memory and battery	Spanning trees, backup topologies, mission-critical applications in diverse topology environments scattered, grid and triangular	Minimum end-to-end delay, least energy consumption, useful for mission-critical applications	Work extension for mission-critical mobileIoT WSNs where mobility shall cause frequent path breakage	Network lifetime, Average E2E delay, Energy consumption, Path length and path establishment time	NS-2	Homo-geneous
1-Cloud, 2017	To balance the energy consumption at the levels of each sensor and of the whole network	Ant Colony Optimization (ACO) and automata network modelization	Fault Tolerant, Improved lifetime with scalability and density, and its precision for better route selection		Dead nodes, Energy consumption of the routes/ dispersion of energy within the best route	Tiny OS Simulator (TOSSIM)	Homo-geneous
EMPR, 2016	To approximate the optimal trade-off between network lifetime and robustness	Multi-objective evolutionary algorithms, k -shortest paths, braided and edge disjoint paths	Performance improved in terms of network connectivity, robustness and lifetime	Improvement in robustness introduced by battery nonlinearities and lack of information about link failure probabilities	Network lifetime, Fragility	Real Time Network	Homo-geneous
MCWC-BMR, 2016	Energy efficient and reliable packet transmission	Cooperative Topology, Braided multi-path routing	Minimized delay, Less collisions due to time schedule strategy	Network coding along with duty cycle can be applied to reduce transmissions	Packet loss rate, PDR, delay, average number of transmissions	TOSSIM, TinyOS	Homo-geneous

Reducing the energy dissipation is crucial to keep the network alive for a longer duration. Clustering is one of the prominent solutions in resolving this issue. During the selection of CHs in WSNs, distance between the node and BS and remaining energy is not taken into account in traditional clustering algorithms. So, a cross layer energy efficient routing algorithm, i.e. CL-LEACH is suggested by Marappan et al. to prolong the network lifetime [35]. In this paper, an energy efficient scheme is developed which considers both factors during the selection of CHs. In this way, sensor nodes having less battery backup than a total energy is not chosen as CH. Energy consumption in the transmission of data from CHs to the BS is directly proportional to the distance between them. So, to transmit the data in energy-efficient manner, relay nodes are selected from one hop neighbors from the neighbor list, also whose residual energy is greater than a particular energy threshold. Route maintenance of the broken links due to mobility of nodes is established by the usage of new route or triggering of new process. Simulation results confirm that CL-LEACH outperforms than LEACH algorithm [36] in terms of number of active nodes, error rate, energy dissipation and message cost.

Energy unbalancing in the network leaves an adverse effect on the lifetime of the network. It is necessary to reduce this adverse effect so as to elongate the lifetime of the network. So, Ding et al. in [37] has proposed an extended approach of popular LEACH algorithm to reduce the uneven energy consumption present in the latter. In case of LEACH, residual energy of the nodes is not considered which induces the hole of energy consumption. So, in DK-LEACH, only those nodes which are having higher energy than the average energy of the network are considered as the candidate for CH selection. Rest part of cluster formation of DK-LEACH and LEACH is same. A function having the proportion of the distance between CHs and non-CHs, and the surplus energy is found out. Minimum value of the function represents that the selected CH has shorter distance to the nodes and higher remaining energy. The adjustment in the proportion is done on the basis of node density. Simulation analysis verifies that DK-LEACH performs better than LEACH algorithm in terms of various parameters such as number of alive nodes, total energy consumption and so on.

Network lifetime can be enhanced by minimizing the energy consumption by the usage of clustering. Random selection of the CHs in LEACH leads to non-uniform energy consumption of the nodes which further degrades the network lifetime. Therefore, Ahmed et al. in [38] have presented a node rank algorithm (NR-LEACH) for the efficient selection of CHs in comparison to LEACH. A weight value is calculated for each node by accounting three factors: RE, number of links with other nodes and distance of out link edges. CHs selection is done on the basis of this weight value. Selected CHs inform other nodes by broadcasting a message using CSMA MAC protocol. Data transmission is done by using TDMA slots so as to manage the data transmission. Simulation results verify that NR-LEACH is doing better than others in terms of average delay, packet delivery ratio, average energy ratio and number of alive nodes.

Increasing the lifetime of the network is the need of hour. To achieve this, many solutions have been suggested and among them one is heterogeneous WSNs. In case of heterogeneous WSNs, selection of CHs is a cumbersome task because of high computational complexity. To overcome this problem, Dutt et al. in [39] have proposed a Cluster-head Restricted Energy Efficient Protocol (CREEP) for the selection of CHs in heterogeneous WSNs. The main motivation behind the work is the requirement of some applications having node mobility such as sensors are tethered to animals or shipping containers. First, to analyze the computational complexity in the selection of CHs, a comparative analysis of some protocols which has been suggested in the literature is done. After that, CHs percentage is estimated in same manner as in DEEC [40], but in CREEP actual and average distance from BS are also considered and this percentage is different w.r.t. normal and advanced nodes. Further, CHs selection is done through the probabilistic approach as suggested in LEACH. Along with that, residual energy is considered as well. So, different threshold values are used for CHs selection with respect to normal and advanced nodes depending on their distance from the BS. Thereafter, depending on the distance between CHs and BS, single-hop and dual-hop communication is used by the nodes. Comparison among the protocols is done by varying the number of CHs. Computational complexity is reduced by limiting the optimal number of CHs out of alive nodes. Simulation analysis shows that CREEP performs well in terms of network lifetime independent of stationary and mobile sensor nodes.

To design and develop energy aware routing protocols in wireless sensor network, a multi-objective clustering algorithm (MFABC) based on fractional calculus (FC) and artificial bee colony (ABC) is suggested by Kumar et al. [41]. Convergence rate of ABC algorithm is controlled by developing this hybrid algorithm. Sink uses optimization technique for the selection of CHs and the fitness function helps in the selection of optimal CHs. Initially, food sources are initialized randomly. Then in employed bee phase, food sources are updated in first half population and new food sources are generated. Fractional calculus is used to improve the predefined solution space by employed bees. Three objectives are considered in the fitness function such as distance travelled, delays and energy consumption to minimize the overall objective. After that, food sources in second half population are updated by onlooker bee. If there is no change in past cycles, scout bee abandon the current food source and initialize new food source randomly. Onlooker and scout bee phases are executed until termination criteria is reached. The best CHs are memorized and communication among the nodes and CHs is done. This process will continue until all the nodes are considered to be as dead nodes. Comparative analysis shows that FABC maximizes the network energy in 65% of the rounds for 100 nodes while 100% of rounds for 50 nodes, more number of alive nodes.

For the optimal routing of the data, Mann et al. in [42] have suggested an energy-efficient hierarchical routing protocol for WSNs based on swarm intelligence (SI), i.e. BEE-SWARM. There are basically three phases in BEE-SWARM protocol: (1) BeeCluster, (2) BeeSearch, (3) BeeCarrier. In BeeCluster phase, the selection of clusters heads is done first and then clusters are formed. For the optimal selection of CHs, artificial bee colony (ABC) metaheuristic technique is used. Three objectives are considered in the fitness function: maximum residual energy, minimize the maximum distance between CHs and BS, minimize the maximum distance between current CH and newly selected CH. Employed bee modifies the existing solution randomly, after that onlooker bee perform a local search. Then improvement in the fitness function is checked by scout bees. In BeeSearch phase, scout bees help in discovering the routes for event communication via two way process, i.e. forward search and backward search using ADV and ACK messages. Former one explores the network while the latter one establishes and maintains the paths between BS and various nodes. In BeeCarrier phase, time division multiple access (TDMA) is used for data transmission. Performance analysis shows that BEE-SWARM is doing much better than other SI-based techniques ERP and MRP in terms packet delivery ratio, total energy consumption, total number of packets delivered and average throughput.

Fundamental challenge in WSNs is scarce energy resources and in the literature, it is observed that clustering is beneficial in saving the energy of the network by avoiding the maximum number of transmissions. Keeping this thought in mind, Khabiri et al. proposed an energy-aware clustering-based routing in WSNs by utilizing cuckoo search optimization technique (COARP) [43]. The algorithm works in two phases: start-up module and register module. In the start-up module, CHs are determined and cluster formation is done. The selection of CHs is done by the sink node using the cuckoo search algorithm. Each member is represented by using a binary string having values $-1, 0, 1$ corresponding to dead, normal and CH nodes respectively. The evaluation of the fitness function is dependent on the average energy of the alive nodes and the threshold. After the selection of final CHs and CMs, four criteria are considered in error function to evaluate each member of the population, namely the residual energy of nodes, distance to the BS, distance between the clusters and within-cluster distances. While in the register module, data transmission is done with TDMA scheduling. Simulation analysis of proposed work indicates that COARP is performing better than other algorithms in terms of first node death on average and packet delivery rate for six different scenarios.

Energy dissipation is believed as one of the major research issue in WSNs. As per research studies, it has been inferred that clustering is one of the best solution to tackle this issue. But the determination of optimal number of CHs is an NP-Hard problem. Based on the conscious distribution of the CHs and their load distribution, [44] proposed an optimized routing algorithm. In this paper, Dehghani et al. have suggested the idea of dividing the network into cellular segments by the BS. All the nodes broadcast the information about node identity, remaining energy and the location to the BS. CHs selection process is handled by the BS. CHs are selected using Genetic algorithm (GA). In GA, binary coding is used. This approach helps in reducing the energy consumption. But GA has slow convergence, so to enhance its speed, GA uses the fixed chromosome length equivalent to the number of nodes whose residual energy is higher in a particular location instead of the average energy of neighboring nodes in the same location to find the maximum number of nodes. Fitness function of GA includes three parameters: residual energy, cluster density and distance of the nodes from CH as well distance of the CHs from BS. To speed up the clustering process, solution produced by GA is transmitted to K-means algorithm. Load distribution is done by limiting the number of the CHs near the sink. Thereafter, data transfer is done using CSMA/CD and radio model. Re-clustering is done when remaining energy of more than half of CHs goes below 20% and after that for 5% reduction in each round. The simulation results depict satisfiable enhancement in booming network lifetime, efficiency, remaining energy and reducing the network delay. Due to proper distribution of CHs via k-means clustering, the time required to transmit the packets to destination is reduced. The limitations of this work are that it takes the assumption that the BS will collect information about the residual energy of the remaining nodes after the node placement occur in the surroundings.

Elongating the lifetime of the network is the necessity of the time. To meet this objective, mobility of the sink node plays a great role in enhancing the lifetime of the network. Mobile sink collects the data from the rendezvous points. This process reduces the tour length and hence end-to-end delay is reduced. But the optimal selection of these points in hierarchical algorithm falls under NP-hard problem [45]. For the effective management of resources, near optimal rendezvous points are found by with the use of meta-heuristic approach, i.e. particle swarm optimization (PSO) called PSOBS. Sink is aware about the position of the sensor nodes and hence it calculates the distance between the nodes, identifies the neighbors, weight value on the basis of number of received packets, and creates traveling sales person (TSP) tree without any exchange of control packets. In this way, a lot of energy gets saved. Solution of PSO is given in terms of an array whose length is same as the number of sensor nodes. Value 1 or 0 signifies whether this point is selected as a rendezvous point or not. Fitness value of the solution should be minimum. Fitness function uses the parameters: Maximum tour length, Length of the route passing through randomly selected RPs, Number of rendezvous points, and Expected number of rendezvous points. Mutation operation is applied after crossover operation to generate the new off-springs. Sensor nodes of a cluster send the data to RPs when mobile sink visits the RP located in that cluster, via single hop communication. So, there is no requirement of Route discovery and route maintenance. Analysis results verify that PSOBS is doing better compared to others in terms of energy consumption, number of rendezvous points, hop count, and hence delay. But the demerit of this algorithm is bit high packet loss.

Minimizing the energy consumption during the data collection in traditional hop-by-hop communication leads to enhanced network lifetime. To address the hot-spot problem which occurs during the data collection in traditional hop-by-hop communication using a static sink, Kaswan et al. in [46] have suggested two algorithms namely Reduced k-Means (RkM) and Delay Balanced Reduced k-Means (DBRkM) by using a mobile sink (MS). RkM focuses on determining the RPs to ensure efficient routing path for MS. DBRkM also focuses on the same problem, but it also confirms permissible delay by considering minimum hop counts and the less hop distance. In both algorithms, initial set of positions of the RPs is determined using k-Means algorithm. Further, it is ensured that sensor nodes communicate with sink node at one hop distance. Final selection of the RPs uses the parameters set of sensor node at one-hop, average hop distance and most desirable distance to calculate a weight value for each node. Thereafter, by using the weight value and cluster size obtained through k-means are used to determine the final RPs. Subsequently, tour cost is calculated via TSP. Further, comparative analysis confirms that DBRkM is outperforming others in terms network lifetime, energy consumption, and number of hop counts.

Traditional hop-by-hop communication used for data collection in the network generally causes an energy unbalancing problem in the network and hence, the network lifetime get degrades. Therefore, to improve the network lifetime by addressing this issue, Tong et al. in [47] have proposed an energy balanced transmission protocol (ETP) based on probability that combines inter slice mixed transmission (IMT) and intra-slice forwarding methods. In this work, they have segregated the problem into further two subproblems, i.e. inter-slice and intra-slice energy balancing problems. They have virtually divided the network area into disk sectors which is further divided into sectors or slices. Inter-slice energy balancing problem has been defined as linear programming problem (LPP) which considers incoming and outgoing flow of data on all the nodes. In this LPP, objective is to maximize the number of events. Each node in the network determines the next slice for the data transmission by using a transmission probability which is determined by considering the data flow. Thereafter, the decision about whether to transmit the data via interslice or intraslice is taken by considering a residual energy, threshold value (δ) and the hop value (σ). Hop value acts as leverage for energy balancing of inter- and intraslices. Simulation results verify that ETP is performing better than other in terms network lifetime, standard deviation in the energy consumption, delay by considering Gini coefficient, and different values of δ and σ.

Efficient routing is very necessary for routing protocol in WSNs because a lot of energy get consumed during the routing process. A protocol to discover the optimal path from source node to destination in WSNs is suggested called as Tabu search based routing algorithm (TSRA) by Hamed et al. [48]. In this algorithm, a focus is given to balance the energy consumption and it is affirmed that all the network nodes dissipate energy equally. Functioning of TSRA is divided into following phases: (1) Initial solution: It basically represents a path between source and destination wireless sensor nodes. In order to optimize the path length, A* algorithm is used. (2) Objective function: In this phase, two parameters are considered, i.e. average energy consumption and average cost of routing, which have to be minimized and network lifetime, which needs to be maximized. (3) Move: To achieve the objectives mentioned in second phase, the selection of next hop node is done using residual energy and the distance between the sender and receiver. Next hop is chosen as the node which is having highest value of $f(x)$. $f(x)$ is ratio of energy to distance. (4) Back-up set: One of the most expensive parts of using the proposed move is the reconstruction of feasible replace paths during the search at different iterations. (5) Neighborhood discovery: A competency function is designed to derive whether a route is good or bad. All feasible moves are examined instead of examining a random move. Competency function is the ratio of average energy versus hop count. (6) Termination Rule: During this phase, stopping criterion of the routing algorithm is defined by a predefined number of iterations. For performance analysis, TSRA is compared with routing algorithms using ant colony optimization (ACO) such as traditional ACO, location-aware routing based on ACO for WSNs, and energy and path aware ACO algorithm for routing of wireless sensor networks, in term of balanced transmission among the node, reduces the energy consumption, routing cost, and extends the network lifetime.

Network lifetime generally degrades not only due to the network operations only but also degrades due to the imbalance in the spatial and temporal activities of the sensor nodes. Thereafter, to improve the trade-off between the energy balancing and energy efficiency, Al-Kiyumi et al. [49] demonstrated a Distributed Energy Aware Fuzzy Logic (DEFL) based routing algorithm by considering heterogeneous nodes (having different initial energy and energy consumption rate). Initially, a benchmark solution (an upper bound basically) is obtained by solving a network lifetime maximization problem using sequential quadratic programming method called *fminimax* solver present in MATLAB. During routing, a fuzzy logic-based approach is used to diagnose the relay probability in the network. Two different kinds of fuzzy systems are used by them to calculate the relay probability. First system handles the input parameter related to remaining energy while second system handles the input related to energy consumption rate which considers remaining energy, transmission energy and energy drain rate. They have observed that higher RE, lower transmission energy and lower drain rate give benefits in the relay decisions. Thereafter, these two cost functions are combined using a weighted function along with a weight parameter toe. The linguistic values used for the input and output parameters are very low, low, medium, high and very high. Thereafter, to find the shortest routes, Bellman Ford Algorithm is used. For choosing the routing path, it is the choice of the individual node and the traffic patterns considered by them are periodic and event trigger based. Further, from the simulation results, they have found that the results obtained by DEFL are almost near to the benchmark solution in terms of network lifetime, normalized RE by considering different values of toe.

6.2. Discussion of multi-path routing protocols

The effectiveness of a routing protocol depends on maximizing the energy efficiency. To make the routing scheme more energy efficient, Sajwan et al. in [50] have suggested an energy-efficient algorithm which takes the maximum advantage of both flat and hierarchical routing protocols. Sink node does the selection of CHs depending on Chance of Election (CE) value which is find out using remaining energy and node density and then it broadcasts this information. Sink creates a Route Set corresponding to each CH which contains all the possible routes between itself and that particular CH. A Legitimate Route Set is created by Sink which contains only those routes on which all the nodes are having residual energy greater than a particular threshold. Once all CHs and routes towards sink are setup, data routing is done. The nodes which are in direct communication range send the data directly. While the nodes which are not in direct range, send in multi-hop manner to their respective CH. While sending the data towards respective CH, next hop is selected using one of the two approaches, i.e. philanthropist (node which is having higher residual energy) and selfish (node which is close to itself than others). For comparison purpose, an extended version of TBC, i.e. M-TBC is also suggested by the authors. M-TBC is tree-based approach in which Intermediate Node Set concept is used to avoid the faster depletion of energy. Simulation results indicate that HEEMP outperforms than existing protocols in terms of First Node Death (FND), number of alive nodes, remaining energy, stability factor and scalability.

In WSNS, energy imbalance is one of the big research issues. To achieve the uniform energy consumption across all the nodes of WSNs and thus to result into prolonged network lifetime, a cluster aided multipath routing protocol (CAMP) is proposed by Sajwan et al. in [51]. In the proposed algorithm, the interested network is divided into virtual zones called grid. The selection of CHs is done by the BS. BS calculates a chance of election value by using three parameters such as residual energy, node degree and distance from sink. The nodes which are in direct communication range of sink node transmit their data directly to sink. The nodes which are not in direct range and at one hop distance from the CH send their data to their respective cluster head directly. While the nodes which are not in the direct communication range of sink or any CH, send their data in multi-hop fashion by using an intelligent routing process (IRP). In IRP, next hop is selected based on the trade-off between the remaining energy of itself and energy required to transmit the packets to its neighbor. If the total number of CHs is more than the number of virtual grids, then additional CHs are assigned to the zones in which number of non-cluster members are more. Energy consumption for all three kinds of nodes is taken as different. Comparative analysis after doing simulation shows that CAMP is doing better than other protocols in terms of first node death, last death, network lifetime, and coverage ratio.

Energy conservation in WSNs is still a big research issue. To cope up with this issue, two approaches, i.e. clustering and load balancing, are considered as effective techniques. To reduce the dropping probability, Gherbi et al. have suggested a novel approach called Hierarchical Energy-Balancing Multipath routing protocol (HEBM) [52]. The algorithm works in seven phases. First phase is the initialization phase, in which announcement message is broadcasted so that each node can calculate its distance from other nodes based on received signal strength. Next phase is the neighbor discovery phase; the objective of this phase is to collect as much information as possible about the neighboring nodes so as to make a better decision in the selection of neighbor. In the next phase, temporary CHs are selected based on a condition (Pch) which uses the following parameters: distance between the node and BS, distance between the node themselves, residual energy and node density. In the next phase, final CHs are selected based on the highest Pch value. Then clusters formation takes place in next phase. Data is transmitted by using the TDMA method. Simulation results confirm that HEBM protocol outperforms others in terms of network lifetime, energy consumption, average remaining energy, average residual energy, average cluster size, latency per packet, average number of dead nodes, FND, HND, LND, etc.

One of the serious research issues in energy limited WSNs is lifetime maximization. To maximize the network lifetime, Senthil et al. in [53] have proposed an algorithm based on cuckoo search optimization, i.e. energy conserving trustworthy multi-path routing algorithm (ECTMRA). Trust and multipath routing techniques are used along with the cuckoo search optimization which results into lifetime maximization. Initially, the network is initialized. After initialization, ECTMRA works in three phases: clustering phase, trust-degree calculation phase, and routing phase. Clustering phase is further divided into four sub-phases. In first subphase, the behavior of the nodes is tested to analyze whether it can become a chief node or not. Thereafter, by using levy flights, a cuckoo is randomly selected. Then cuckoo search is used to select the CHs in next subphase by evaluating the fitness. Fitness function uses two parameters mainly: consumed and current energy of the nodes. Then clusters are formed and at the end, CHs are recycled to lessen the over burden on one chief node. In next phase, trust degree is computed by using the parameters, i.e. packet consistency factor, forwarding rate factor, battery backup, node and path trust evaluation. Then at the end, routing is performed by searching for the route from routing table. Analysis results confirm that ECTMRA outperforms other protocols in terms of PDR, average latency, Energy consumption ratio, network lifetime, and routing overhead.

In WSNs, finding the optimal routes is a big problem due to scarce energy resources, dynamicity and heterogeneity. Also, energy hole problem persists near to sink which leads to fast drain in the energy. To mitigate the hotspot problem, Deepa et al. in [54] have suggested a protocol called as Optimized QoS-based Clustering with Multipath Routing Protocol (OQoS-CMRP). In this protocol, a meta-heuristic technique, i.e. modified particle swarm optimization (PSO) is used to select the CHs on the basis of received signal strength. In fitness function, network parameters such as number of cluster members, energy and distance between the nodes are taken into account. After the cluster formation phase, the performance of the links is evaluated to ensure the QoS. Link quality is measured in terms of reliability, energy , and delay. There is a multi-hop communication between wireless nodes and BS. For multi-hop communication, the selection of next hop neighbors is done using greedy algorithm, i.e. Single Sink-All Destination algorithm. For transferring the data to the sink, round-robin path selection algorithm is utilized to select the best paths. At regular interval of time, the process of rerouting and re-clustering is initiated by sink. Re-clustering basically happens when the residual energy of any node falls below a particular threshold. Simulation results verify that OQoS-CMRP outperforms others in terms of packet delivery ratio, network lifetime, total energy consumption, throughput and end-to-end delay.

Preserving the energy is very necessary for WSNs especially when the wireless nodes are deployed in areas of event monitoring in which data is required on a real-time basis. This work focuses on finding the solution for event-driven dynamic clustering algorithm by the use of biological immune system. A lot of energy get consumed during re-clustering and rebuilding of the routes. So, when similar kind of events happens again in future, same cluster structure and routing paths are used by using biological immune system to minimize the energy consumption, i.e. rule-driven multi-path routing algorithm with dynamic immune clustering (RDICMR) which is given by Ding et al. [55]. First, the whole network system is initialized. BS collects the information about area position, hard and soft threshold from the nodes as in TEEN [56]. The duration, till no event does occur, nodes are in dormant state. Judgment about the event triggering is done using trigger rules. Thereafter, if the triggered events satisfy the affinity and energy rule as well, cluster structure is copied and routing paths with highest affinity are selected, then data transmission is done. If the affinity and energy rules are not satisfied, then CHs selection is done. CHs are selected similarly as in LEACH but here distance and energy are also considered. Next hop among the multiple paths is chosen on the basis of communication cost. This cluster structure and routing paths are saved after it. When the lifetime of the clusters get ended, all the clusters are dissolved and it turns back to initialization. This process continues until all the nodes depletes their energy. Performance analysis shows that RDICMR outperforms others in terms of network lifetime, residual energy, amount of data transmitted.

To mitigate the problem of unbalanced energy consumption, Tanessakulwattana et al. have suggested a multi-hop, multi-path-based distributed algorithm known as Multipath Energy Balancing (MEB) [57]. Network is divided into equal size regions with all regions having same node density. Maximum number of appropriate regions are also estimated. To become a CH, each wireless node competes with nearby sensor nodes and CHs selection is done by considering residual energy. Cluster formation is done by using CH-advertisement and CH-association message. Once the cluster formation and CHs are set up, CHs aggregate the data and transmit it to the sink via selected CHs. To reduce the energy usage of CHs during inter-cluster transmission, it is assumed that a CH can transmit the data via using two paths only, i.e. either it will send the data to the CH in the next region or next-to-next region only. Transmission ratio corresponding to two different regions is estimated so as to balance the energy consumption. Inter-cluster energy consumption determines the lifetime of the CHs. It is also decided, after how many data collection rounds, re-clustering and re-routing need to be done (i.e. procrastination period). Non-persistent carrier sense multiple access (CSMA), time division multiple access and direct sequence spread spectrum (DSSS) are used for intra-cluster communication. Simulation results verify that MEB is doing better than other protocols in terms network lifetime specifically when the cluster size is small.

Earlier multi-path routing protocols in the area of WSNs suffer from various challenges such as limited resources and low quality of service. A hierarchical, multi-path routing protocol for WSNs (HMR-WSN) to remove the weaknesses of earlier multi-path routing protocols like severe consumption of the resources, permanent usage of optimal paths, low scalability and accuracy, less security was suggested by Hossein et al. in [58]. In this protocol, time division is done via number of super-rounds where each super round refers to few time intervals. In first super round, CHs are selected in a random manner. Then in next super round, each cluster head selects multiple CHs on the basis of ranking for the corresponding cluster. Ranking is done by using the parameters residual energy, delay, accuracy of arriving data from the cluster's member, number of times a node is selected as CH in previous rounds. Linear, Saati, and Euclidian normalization are used to assign the weights. Traffic load is distributed among all the CHs. Finally each CH aggregates the data and forward to the sink. From statistical simulation and algorithmic complexity, it is inferred that HMR-WSN outperforms other protocols in terms of average packet delivery, total energy consumption, average rate of packet loss, throughput, and accuracy.

Some applications are assumed as loss and delay intolerant like mission critical applications. Protocols discussed in the literature are based on reactive classes and hence the delay is very high. Also, single link failures are handled in proactive class but convergence time to solve the problem of multiple failure recovery is still a big issue. So, to handle the multiple failures in an energy efficient and timely manner for mission critical applications, a Fast Rerouting Protocol (FRP) is proposed by Riaz et al. in [59]. To shift the traffic immediately to a new route, it is required that backup route is readily available with no or less delay. Benefit of backup routes is that there is no need of new path discovery and it will result into lesser convergence time delay. So, before any transmission between source and destination, at least one backup path is created in between. Path Request (PREQ) and Path Reply (PREP) packets are used to find the primary path. When a node receives PREP packet, then instead of unicasting PREP alone, it broadcasts Backup Route Request (BREQ) as well. To establish the alternate paths between intermediate node and destination, a time-to-live timer is attached to BREQ message. Backup Reply (BREP) is generated when BREQ reaches at a node towards destination or at the destination itself. After that, during the data transmission, when failure occurs at next hop, the node sends the traffic through shortest backup route. Simulation results depict that control messages transmitted and the amount of time taken to do faster rerouting is very less. Also, end-to-end delay, energy dissipation are very less and hence the network lifetime is very high compared to other protocols.

During the data gathering and routing process, an inherent problem of unbalanced energy consumption arises in WSNs due to limited energy resources. So, a load balancing algorithm has been suggested by Laouid et al. to moderate this issue in [60]. Residual energy of the nodes and discovery of the best routes by using hop value and then inserting the routes into routing table are considered. Ant colony optimization and automata network modelization are the two basic ideas behind this approach. With increasing path length and network density, the precision to select the best path grows. Simulation results show that in this paper, best path is selected leading to less energy consumption, improved scalability, and more fault tolerance power.

In most of the literature, focus is given on enhancing the network lifetime only which may be detrimental to the robustness. Additional robustness against link failure gets added by the use of multipath routing in WSNs. But in resource constrained WSNs, it is required to know that by choosing which path network lifetime get maximized. To find the optimal trade-off between lifetime and robustness, Rahat et al. have proposed a multi-objective elitist evolutionary algorithm based protocol (i.e. EMPR) [61]. A new parameter, i.e. fragility, is introduced to measure the robustness. Multi-path routing scheme is defined in terms of routes and time shares. Then, network lifetime of all the paths which involves a particular node is determined in terms of energy consumption on respective path along with its active time share. Then, lifetime of the node which is having minimum value is maximized and optimal time shares are calculated using linear program. Thereafter, fragility is determined in terms of time shares and number of messages sent. Traffic distribution between the paths is find out by solving the combinatorial optimization problem by using multi-objective evolutionary algorithm. Objectives of optimization problem include maximizing network lifetime and minimizing the fragility. To find the potential good routes, search space is pruned by the use of k-shortest paths, braided and edge disjoint paths and in this way, efficiency is achieved. Experiments are done on real networks. However, uncertainties caused by lack of information about link failure probabilities have been neglected in this paper. Analysis results demonstrate that this algorithm achieves better network lifetime for different value of sensor nodes compared to braided multi-path scheme.

Energy efficient and reliable packet transmissions over the wireless links in WSNs are very necessary for critical applications. So, to collect the data while meeting these objectives, Xinjiang et al. in [62] have proposed an algorithm, i.e. distributed width-controllable braided multi-path routing (WC-BMR) in which local information is taken as basis. But WC-BMR is found to be less co-operative. So, multi-cooperative WC-BMR (MCWC-BMR) has been suggested further by the same authors. Heterogeneous widths and a novel time schedule strategy have been considered. Reliability has been achieved with the use of multiple parent cooperative topology (MPCT) in which every node has multiple potential parent for forwarding their data. On the basis of channel qualities with the neighbors, parents set are determined. After this, packets are delivered using time scheduled strategy (TSS). The idea behind TSS is to avoid the collision and packet loss. In TSS, along with the best routes which are used in the literature, other links are also considered to provide the high reliability. In this paper, a modified cooperative topology has also been suggested to ensure the reliability and efficiency. In this, nodes having high priority forward their data first and priority is maintained using parent set. Performance analysis shows that MCWC-BMR is performing well in terms of energy efficiency, reliability, and delay.

7. Comparison and analysis

7.1. Comparative analysis of routing protocols on the basis of their objectives

As we have discussed earlier, every routing protocol has some specific objectives. To achieve these objectives, different authors have used different methodologies in their works. We have tried to bring classification tree among various objectives, sub-objectives and the approaches that try to achieve them. Figure 6 gives a summarized graphical form of this classification. Researchers may utilize this classification tree to understand the contribution of the methods/approaches to achieve the various objectives.

In this section, we will compare single and multi-path routing based protocols one after another.

7.1.1. Single path routing protocols

One of the main and common objective of [33–35,37–39,41–49] is to elongate the lifetime of WSNs. As we know, clustering is one of the good approaches in reducing the energy consumption of the sensor nodes and selection of CHs is a very tedious task. So, all routing protocols, in which clustering is used, they have generally following phases: CHs Selection, Route (Optimized) Discovery towards sink via CHs, Data transmission. Most of the authors have not done work with route maintenance phase. In [33–35,37–39,41–44], clustered environment is considered while in [45–49] non-clustered environment is present.

In [33–35], to enhance the network lifetime, focus is given on the optimal selection of CHs and optimized route discovery and route maintenance. In CHRA [34], optimal number of CHs is also determined and it has considered heterogeneous network, while in WECRR [33] and CL-LEACH [35], both the things are not considered. In CHRA, the selection of CHs is done using probabilistic approach as in LEACH-C using centralized approach, while WECRR selects the CHs locally using a weight function which considers the parameters: residual energy, node centrality and distance to the BS. In CL-LEACH, CHs selection is also done locally via the algorithmic approach by considering the parameters: residual energy and distance from the BS. In CHRA, optimal placement of CHs is done using MIP which further helps in uniform energy consumption of the network. Overall process of CHRA is more complex than WECRR in terms of energy in comparison to probabilistic approach, but more accurate results can be obtained using it. Thereafter, in WECRR, optimized routes are discovered using multi-facet attributes like energy efficiency of routes, packet error probability and congestion, while in CHRA, residual energy and distance to BS are considered and in CL-LEACH, routes discovery is done by considering some energy threshold ($S(m)$) only. This kind of optimized routes discovery in both helps in balancing the energy consumption. Subsequently, to make system more reliable in WECRR and CL-LEACH, route maintenance has also been taken care of, which was absent in CHRA. WECRR is observed as most trustworthy protocol among WECRR, CHRA and CL-LEACH because WECRR considers multi-facet attributes during route discovery process. In all WECRR, CHRA and CL-LEACH, delay has been minimized because of the consideration of optimal routes.

In [37–39] also, authors have suggested the idea of minimizing the energy consumption via optimal selection of CHs and hence, prolonging the lifetime of the network. But they differ from WECRR, CHRA, CL-LEACH in certain sense. DK-LEACH [37] have performed the CHs selection using the idea of LEACH algorithm and in NR-LEACH [38], CHs selection is done using a weighted function. While in CREEP [39], CHs are selected by integrating the ideas of LEACH and DEEC algorithms which is more intuitive. Because CHs selection is energy consuming, so computational complexity by varying number of CHs is also determined in CREEP2018. Subsequently, in DK-LEACH2017, non-CH nodes join the CHs using a function value which is dependent on initial energy, residual energy, distance of the node from BS, and the maximum distance from BS; in NR-LEACH, CHs broadcast a message using CSMA MAC protocol; while in CREEP, non-CH nodes join their respective CHs by dual hop communication. This kind of decision-based route discovery in DK-LEACH helps in keeping the nodes alive for a longer duration and delay may also be less compared to CREEP. In DK-LEACH and NR-LEACH, data transmission is done in TDMA slots which helps in avoiding collisions and hence minimizing the energy consumption, while it is not used in CREEP. Although, route maintenance is not handled in these as in CHRA. So, specific contribution is not done in these compared to WECRR and CL-LEACH. Because of the absence of optimized routes discovery in these, delay and reliablity are found to be on downside in DK-LEACH and CREEP. NR-LEACH is found to be delay aware and collision avoidance is also handled.

In [41–46], main focus is to elongate the lifetime of the network by solving the NP-hard problem of optimal selection of CHs, via fitness functions which are further solved by exploiting some meta-heuristic techniques. In [41–44], this kind of optimal selection of CHs helps in minimizing the energy consumption. But, every work has designed the fitness function by considering different parameters. In MFABC [41], network lifetime has been enhanced by the consideration of different parameters in the fitness function of Artificial Bee Colony (ABC) algorithm such as distance traveled, energy consumption, and delay for the optimal selection of CHs. While in BEE-SWARM [42], network lifetime is elongated by designating those nodes as CHs which have maximum remaining energy (RE), minimum distance between CHs and BS, also minimum distance between current CH and the newly chosen CH and finding the solution by using ABC algorithm as done in MFABC. In COARP [43], RE, distance to the BS, within-cluster distances and between cluster distances are considered as the fitness function parameters for cuckoo search algorithm. And in EEACBR [44], the parameters considered in the fitness function of genetic algorithm (GA) are distance between ordinary nodes to the BS, total distance between nodes to the CHs, and the distance between CH and BS, total number of sensor nodes, and number of CHs. Although, both MFABC and BEE-SWARM have used the ABC algorithm to solve the fitness function, but they have considered different parameters. In BEE-SWARM, no focus is given on intra-cluster distances, along with that, they have improved the initial population randomly while [41] has considered the intra-cluster distances as well as in [41], fractional calculus is used to improve the solution. These both factors help [41] in minimizing the energy consumption of the nodes further. [44] considered almost similar parameters as that although, the parameters of MFABC and EEACBR are similar, but in EEACBR, K-means clustering is used to speed up the clustering process. This results into lesser delay in EEACBR while in MFABC, BEE-SWARM and COARP, delay is not considered. Also, cellular segmentation of the network is also done for the uniform distribution of CHs in EEACBR [44], so energy consumption is further minimized. But, in all of these, data transmission is done using TDMA, results into collision avoidance, but route maintenance is not taken care of.

In [45–49], main focus is to elongate the lifetime of the network by minimizing the energy consumption during the data collection. But they have not focused on minimizing the energy consumption via optimal selection of CHs which was considered in [33–35,37–39,41–44]. So, first, they are different from others in this sense. After that, in PSOBS [45] and DBRkM [46], sink collects the data from the sensor nodes one-hop distance by moving onto RPs using traveling salesperson problem (TSP), it helps in minimizing the delay as well as energy consumption of the sensor nodes is also less because nodes have to transmit their data to one-hop distance only. Difference in PSOBS and DBRkM lies in the selection of RPs. In PSOBS, RPs are selected by solving the fitness function using PSO and in DBRkM, RPs are selected using k-means and weighted approach. And in case of ETP [47], energy consumption problem is minimized by the slice-based model. Then, in TSRA [48] and DEFL [49], sink is static, but to minimize the energy consumption, shortest paths are selected by using A* algorithm, fuzzy logic, Bellman Ford algorithm. In terms of delay and reliability, TSRA and DEFL are on downside compared to PSOBS.

7.1.2. Multi-path routing protocols

In multi-path routing as well, all the routing protocols have one common objective, i.e. to elongate the lifetime of WSNs. In the literature, the selection of CHs is considered as NP-hard problem but clustering has their own benefits as well. In [50–55,57,58], multi-path routing along with clustering has been suggested while in [59–62], clustering is not considered.

Further, in [50–52], to enhance the network lifetime, focus is given on the optimal selection of CHs and route discovery. Route maintenance phase is not considered in them. CHs selection is done in HEEMP [50] by computing a *CE* value by exploiting the parameters: residual energy and node degree, then on the basis of *CE* and energy threshold, CHs selection is done, while in CAMP [51], *CE* value is calculated by using the parameters: residual energy, node degree and distance of the nodes from sink. Then in HEBM [52], CHs selection is done by finding the *Pch* value on the basis of distance between the node and BS, distance between the node themselves, residual energy and node density. Consideration of node density and sleep-wake-up scheduling in HEBM helps in minimizing the energy consumption further compared to HEEMP and CAMP. Final CHs selection in all of them is done on the basis of higher *CE*, *Pch* and threshold values. In HEEMP, CHs are uniformly selected by using *CE* and distance threshold and, in HEBM, the selection of CHs is done through a join condition which uses *Pch* and distance threshold, while in CAMP, distribution is done by using the concept of virtual zones. But, in CAMP, when number of CHs are more than the zones, uniformity loses, also such type of network scenarios can't be applicable on large-scale network. Subsequently, data routing is done in HEEMP through selfish and philanthropist mode which use distance and energy parameters respectively, while in CAMP, routing is accomplished via IRP which depends on RE and energy dissipation, and in HEBM, data routing is done by using TDMA slots which ensure less collisions and hence less delay as well, while in HEEMP and CAMP have not considered this factor. Further, latency is also less in HEBM. In HEEMP and CAMP, delay and reliability are not accounted.

In ECTMRA [53] and OQoS-CMRP [54], fitness function is utilized for the optimal selection of CHs and hence, to prolong the network lifetime. The protocol ECTMRA have used the cuckoo search algorithm whose fitness function considers the parameters: residual energy and energy consumption, while OQoS-CMRP have utilized distance, residual energy, and cluster density as the parameters of PSO algorithm. Thereafter, in ECTMRA, in route discovery phase, trust score estimation is done which ensures trustworthy routing in terms of less latency and more reliability, while in OQoS-CMRP, route discovery is done by solving a multi-objective function having reliability, energy, and delay metric, and confirms about less delay and better reliability. But, in OQoS-CMRP, a lot of energy get consumed because re-clustering and re-routing happen every time, when RE of a node goes below a particular threshold. Then, to minimize the re-clustering and re-routing process, in RDICMR [55], a different approach is considered to mitigate this problem. In RDICMR, first CHs selection is done by extending the idea of LEACH algorithm, also including RE and distance to the BS in this process. Thereafter, route discovery is done on the basis of communication cost of the route. Further, to mitigate the energy consumption of re-clustering and re-routing, biological immune system is used to memorize the clustering process over the rounds and when similar kind of events occur, previously stored clustering information is used instead of doing clustering again, in this way, it minimizes the re-clustering and re-routing process. But, RDICMR is neutral in terms of delay and reliability in comparison to OQoS-CMRP. After that in MEB [57], CHs selection is done in probabilistic manner by considering initial and consumed energy. Further, uniform energy consumption of each node in this is ensured by routing of the data over short distances, i.e. only to next two regions only. But, in reality, dividing a network into equal sized regions is a challenging task. In HMR-WSN [58], CHs selection, formation has been done by considering many parameters which may result into better lifetime as discussed earlier. But, it requires a lot of computation (as discussed in previous section) to carry out this process and hence energy consumption will be more. But, to balance the energy consumption, load balancing is done as well.

In [59–62], main focus is to minimize the energy consumption. But, they have not considered the clustered environment. In FRP [59], energy consumption is minimized by avoiding the long back-up routes, also for establishing the back-up routes, number of transmissions and hence, the traffic overheads were reduced by the usage of BREQ msg along with PREP message. These help in prolonging the lifetime of the network. While, in 1-CLOUD [60], distribution algorithm helps in balancing the energy consumption. Also, less number of control packets are transmitted into environment, because broadcasting of RREQ message happens only after a specific duration which leads to less delay. In EMPR [61], evolutionary multi-path routing based solution helps in minimizing the fragility and then multi-path routing by the usage of active time shares helps in enhancing the network lifetime. Pruning of the search space by using braided and k shortest paths further minimizes the energy consumption. While, in MCWC-BMR [62], opportunistic routing helps in the selection of best forwarders, nodes with same or less hop count are selected as forwarders which help in minimizing the energy consumption. Transmission overheads are reduced because of co-operation between the same level nodes. In [59–62], only FRP and 1-CLOUD are ensuring about delay and reliability.

7.2. Analysis of routing protocols on the basis of various features

As we know, each routing protocol has some basic features such as their objectives, what methodologies are used to achieve those objective, what kind of benefits can be reaped by achieving the objectives, what are the loopholes which still require improvement so as to enhance the overall efficacy of the protocol, what type of parameters are used to evaluate the performance of specific protocol, what kind of a simulator is used to measure the efficiency of the protocol and what type of environment has been considered. So, in this section, we will do the similar kind of analysis.

7.2.1. Features based analysis of single path routing protocols

A feature analysis of routing protocols based on single path routing is described in Table 2.

7.2.2. Features based analysis of multi-path routing protocols

A feature analysis of routing protocols based on multi-path routing is described in Table 3.

8. Future directions

- To develop a routing protocol that provides self-configuration and route maintenance of sensor nodes to sink being deployed in harsh and unattended environment, to elongate the lifetime of the network.
- Selection of CHs is the prominent challenge in clustered environment which decides how long the network is going to alive. So, to develop a routing protocol that ensures the optimal selection of CHs and also, determine what should be the optimal cluster size, thereby results into enhanced network lifetime, can be good contribution.
- Data delivered late or partial data lost has no significance. To ensure the data delivery on time along with maintaining its integrity (reliability) in WSNs routing protocols that are designed for sensitive application areas.
- In WSNs, finding multiple paths from different portions of the field helps in distributing the data traffic evenly among all the routes. So to propose a routing protocol that determines how many routing paths are optimal and finding the optimal paths.
- When multiple paths are found out, then designing a routing protocol that ensures maintenance of the discovered paths, keeps the network connected for a longer duration without any data loss and also keeps the data secure.
- Most energy consuming operation is the communication. So, designing a routing protocol that confirms less number of retransmissions of data between sensor nodes and BS, and less number of control packets overhead while discovering multiple paths so as to minimize the energy consumption of the sensor nodes.

9. Conclusion

In WSNs, energy-efficient routing is still a big challenge. Despite research community has suggested various solutions to counter this issue, but most of the solutions only reduce certain amount of energy consumption. To design a protocol that can enhance the lifetime of the routing protocols in WSNs, an essential step would be to review the available solutions for efficient data routing and prolonging the network lifetime. In this review article, we have reviewed and examined various energy-efficient routing protocols based on single-path and multi-path routing. And we have done classifications of routing protocols on the basis of operations and the objectives after analyzing the papers based on single path and multi-path routing protocols. Thereafter, we have analyzed the protocols on the basis of various features. Subsequently, one another taxonomy pertaining to different approaches used to achieve a specific objective, which are utilized by the researchers in their papers discussed in this review, is proposed. We have also done a detailed comparative study of single path and multi-path routing protocols by highlighting their strength and weakness on the basis of the objectives. After above discussion, future directions have been given which can help researchers to identify the area of contribution in which they can do work with the aim to obtain an optimum solution with negligible drawbacks or limitations found for previously developed solutions.

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