Received: 5 July 2023 | Revised: 8 September 2023 | Accepted: 15 October 2023

DOI: 10.1002/ett.4888

Computational intelligence techniques for energy efficient routing protocols in wireless sensor networks: A critique

M. Sri Lakshmi[1] | K. Seshadri Ramana[2] | Gandikota Ramu[3] | K. Shyam Sunder Reddy[4] | C. Sasikala[5] | G. Ramesh[6]

[1]Department of CSE, G.Pullaiah college of Engineering and Technology, Kurnool, India

[2]Department of CSE, Ravindra College of Engineering for Women, Kurnool, India

[3]Department of CSE, Institute of Aeronautical Engineering, Hyderabad, India

[4]Department of CSE, Maturi Venkata Subba Rao (MVSR) Engineering College, Hyderabad, India

[5]Department of CSE, Srinivasa Ramanujan Institute of Technology, Anantapuramu, India

[6]Department of CSE, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India

Correspondence
Gandikota Ramu, Department of CSE, Institute of Aeronautical Engineering, Hyderabad, Telangana 500043, India.
Email: ramugandikota9@gmail.com

Abstract

Wireless Sensor Networks (WSNs) play a pivotal role in modern data acquisition systems, but their energy-efficient operation remains a significant challenge. This work provides a concise overview of the key challenges and proposed solutions discussed in the context of energy-efficient routing protocols for WSNs based on a systematic literature review. The need for fault tolerance to ensure network resilience is vital, given the limited resources and environmental challenges faced by sensor nodes. This work emphasizes the importance of addressing several open research questions, including the integration of diverse topologies, cross-layer routing, and the use of multiple mobile sinks. Additionally, it highlights the need for QoS-aware routing for real-time applications, mathematical modeling for protocol evaluation, and the challenges of testing routing protocols on real hardware. Furthermore, this article suggests leveraging the RPL routing protocol with the Node-based Metric RNE for enhanced energy efficiency and explores the promising field of hierarchical routing protocols, exemplified by the LEACH protocol and its variants. This work serves as a roadmap for researchers and practitioners, identifying critical challenges and proposing directions for future research to achieve energy-efficient routing protocols in WSNs, ultimately enabling effective communication in resource-constrained environments.

1 | INTRODUCTION

Recent years of computing have evidenced that WSNs as a progressive area of research in networking and computer communications.[1] The popularity of WSNs is due to their capability of deploying low-cost and low-power sensor nodes (SN) to monitor the physical and environmental changes of a particular geographic location over the internet. In general, the composition of the WSNs includes the process of deploying a larger number of SN along with a limited number of base stations such that when deployed in a geographic location, SN autonomously communicates with the other nodes within the network to sense, aggregate and process the information of a particular region and transfer the same data to the base station.[2] Base stations are equipped with unlimited power that enhances their complex capabilities, making them a gateway for other networks to process the distributed information. SN often has a finite amount of energy and must conserve it to extend its lifespan. When an SN battery runs out, it's thought to be dead. An SN uses energy for sensing, data processing, and communication, the latter of which uses the most energy. Many solutions assume that data collection uses far less energy than data transmission,[3] a critical need in WSN.

There is no best protocol, but there is the most suitable protocol for a specific application. In fact, to the best of my knowledge, all the existing protocols are application-specific, and the performance highlighted in the papers depends on the context of their use. The WSNs consume less transmission energy than the major network. The WSNs based on a hybrid network configuration may be optimum concerning the nodes' transmission and processing energy. Using cluster heads and forming smaller major networks saves transmission and processing energy. Several research studies have contributed to developing various routing algorithms addressing the characteristics of WSNs and their network structure. Based on the topology of deployment, the WSNs have been broadly classified into three variants: Hierarchical routing protocols (HRP), Flat routing protocols (FRP), and Location-based routing protocols (LBR). In the context of hierarchical routing, the SN within the network is autonomously organized into clusters such that the node with higher energy is considered a cluster head.[4]

The election of the cluster head is made by considering the efficiency of the node such that the cluster head should be capable of handling several complex operations, which include the collection of data within the cluster from various nodes, aggregating the data in the context of reducing the complexity and finally communicating the data toward the base station.[5] The energy hole problem is caused by a lack of energy consumption management in the many-to-one traffic scheme, which results in the rapid loss and destruction of energy resources of nodes near the sink. The energy hole problem and the periodic choice of the ideal path affect the lifetime of WSNs in most routing algorithms. The network will be partitioned due to these two issues, and the WSN will be unable to perform its vital job. The main issue with such routing strategies is that they reduce total energy usage at the expense of network energy drainage, which is inconsistent.

In flat routing, the SN is assigned a minor task. The nodes inside the network should be able to sense information based on directed diffusion (DD) protocol and sensor protocols (SP) for information via negotiation. Finally, in the case of LBR, the geographical location where the SN is deployed is to be identified based on which the routing parts are generated to words the base station is based on greedy perimeter stateless routing and geography adaptive routing protocol. The wireless sensor (WS) node is shown in Figure 1.

The general assumption made in recent studies while developing the clustering algorithms for WSNs is that the SN is considered static. The network topology is simple as the location information of the nodes could be easily maintained.[6] The transfer and acceptance of data packets are the main sources of power consumption on WSNs. As a result, we must properly manage and regulate the use of power to create protocols for the WSN-powered route. This is the driving force behind this study. The most difficult part of SN is that nodes inside WSNs are constrained in computing power, storage, and battery backup, which impacts their communication capabilities. As a result, much research is required to build energy-efficient routing methods that can be maintained in the network for an extended period. Practical difficulties such as trade-offs owing to energy-delay, energy throughput, and energy reliability are avoided in this situation. However, there seems to be no comprehensive research that explains the importance, concepts, and principles of WSN power line strategies.

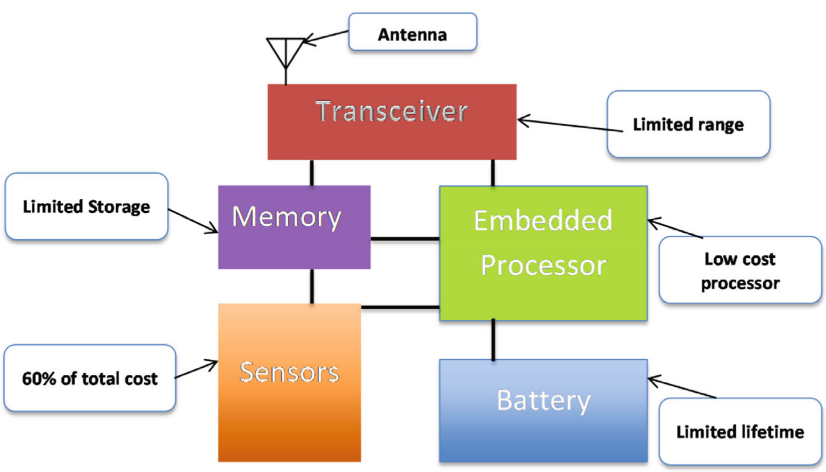

FIGURE 1 WS node.

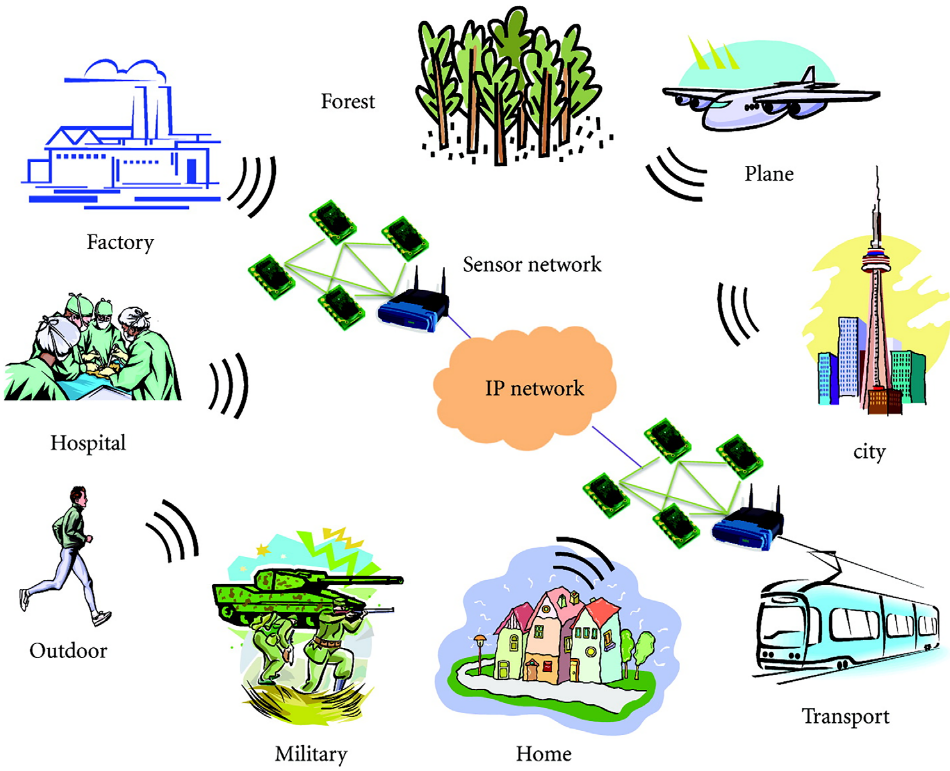

FIGURE 2 Energy-aware WSN applications.

Our responses to the survey are listed below. As described in Section 2, researchers have published some survey articles to evaluate and classify the performance of various energy-efficient routing algorithms for WSNs. A few applications for WSNs that use efficient energy resources are shown in Figure 2.

This survey article goes through the energy-efficient and energy-efficient WSN routes in greater depth. As a result, it provides a detailed analysis of the most efficient and medium-term power protocol aimed at reducing power consumption on WSNs and thus extending network life. The study raises taxonomy to demonstrate the RP tested based on its BS communication method and the techniques used in its application. Table 1 summarizes the advantages and disadvantages of energy systems.

We also divided the surveyed RP into categories based on the solution types or algorithms used in the routing algorithm and the decision factors used. The benefits and drawbacks of the choice factors used in developing various RP are also investigated. Finally, this survey recommends potential research areas for optimizing energy use in SNs as a critique. The results of this survey should help researchers and staff in the field better understand energy-efficient and balanced energy systems and make decisions based on their application needs and network design. The main purpose of the research study is to analyze the advanced research methods discussed in the context of solving energy efficiency issues while developing an advanced WSN route protocol. In this scenario of conducting a systematic review, in Section 2 of the article, we describe the process of research methodology and review protocol for a systematic examination of existing energy-efficient protocols and Section 3 includes the detailed context of the problem statement, Section 4 includes the review of various energy-efficient RP, Section 5 presents the analysis of the study and open challenges and research gaps, and in Section 6 article is concluded.

2 | RESEARCH METHODOLOGY

The Systematic literature review (SLR) aims to enable the succeeding researchers with the scope of research in WSNs for emerging energy-efficient protocols. Although several SLRs have been published to address various challenges in developing efficient protocols in WSNs, it found a need for well-interpreted SLRs that address the key algorithms involved in

TABLE 1 Advantages and disadvantages of energy optimization protocols.

Protocol	Advantages	Problem Addressed	Disadvantages
EnOR[7]	Prolonging the network lifetime by balancing Energy consumption	The immutable transmission priority level of the node's single-hop performance	Void hole problem by fixed network structure
WALL[8]	Minimizing end-to-end delay and maximizing network lifetime	Single hop performance	A limited area, and simple localization method
EBLE[9]	Prolonging the network lifetime by energy efficiency	Energy limitation	Packets broadcast, and data delay in transmission
QL-EEBDG[10]	Balancing the energy using intelligent algorithms	Void hole, Energy imbalance	Transmission delay, and high energy consumption
RECRP[11]	Energy efficiency using cross-layer design	Challenges of UWSNs	Complex implementation, and huge packet overhead
TORA[12]	Prolonging the network lifetime by the scheme of hierarchical localization	Limitation of data collection	High consumption of energy
HyDRO[13]	High throughput, and low energy consumption	Short network lifetime	Void hole problem by packet broadcast
LFEER[14]	Prolonging the network lifetime by energy efficiency	Channel limitations	Complicated and unreliable link calculation
MARL[15]	Maximize network lifetime using intelligent algorithms	Dynamic topology	Huge packet overhead, and energy consumption
EGBLOAD[16]	Maximize network lifetime by reducing data load	Intermediatory nodes	Void hole problem to high energy consumption
SEECR[17]	Enhancing network performance by embedding a defense mechanism	Network security attacks	Void hole problem by high data overhead
COARP[106]	Energy-conscious routing methods are introduced	Aimed at WSNs with stationary sensor nodes	The solution is not suitable for managing mobile sensor nodes
FLDEAR[108]	Used for delay-tolerant mobile sensor networks	Aims to improve data packet delivery rates and alleviate data transmission overhead	Load balancing and Routing are not fully optimized.

TABLE 2 Dissemination of identified papers through some scientific databases.

S. No	Database	No. of papers
1	ACM	19
2	IEEE	35
3	SCIENCE DIRECT	21
4	SPRINGER	24
5	TAILOR and FRANCIS	15
Total		114

developing energy-efficient protocols in WSNs. Initially, a review protocol is defined, which allows the formulation of initial Research Questions (RQs) based on a systematic search of over-indexed journal databases using specific keywords related to the WSNs domain to identify recent related studies in the context of devising efficient algorithms for computation in SN. In the second phase of the review methodology, preliminary research relating to the topic is chosen based on the stated criteria, as shown in Table 2.

TABLE 3 Research questions formulation.

Definition	Motivation	Research question
Problem	Gain knowledge related to in-depth analysis of various RP in WSNs	*RQ1*: What are various efficient RP in WSNs?
Intervention	Understand the state of art algorithms and protocols involved in developing efficient WSNs	*RQ2*: Which state-of-art algorithms and protocol designs have mitigated challenges like delay, energy efficiency, and network lifetime within WSNs?
Comparison	Comparative analysis of existing protocols and algorithms that influence the performance of WSNs	*RQ3*: Generate an Analysis of various existing techniques and protocols in WSNs
Outcome	Identify open research issues and challenges in WSNs	*RQ4*: What is the future scope of research in WSNs

TABLE 4 Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Algorithm-centric approaches, protocols, and mathematical statements meant to solve efficient routing in WSNs are covered in these articles.	Articles that include ambiguity in terms of implementation tools and data sets
Articles based on empirical research with well-defined implementation details and simulation findings and the inclusion of tools and datasets essential for the simulation of RP in WSNs.	White papers and lecture notes on the architectural perspective of WSNs have been published.
Articles that are mostly used in the field of computer science	Articles are written in a language other than English
The texts are written in the English language	

2.1 | Defining research questions

Formulating research questions is important in evaluating an SLR since it involves the rationale and necessity for performing a systematic review. The PICO technique is used while generating well-built research questions in the context of yielding high-level evidence that supports the review's outcome, based on the motivation received.[18] The research questionnaire is formulated as shown in Table 3.

2.2 | Preliminary assortment analysis

One hundred forty-eight articles are discovered from scientific databases in the preliminary phase of the selection using the search strings listed in Table 2, and the articles are initially scrutinized by examining the relevance of the article title to the problem statement. Articles are selected in the second step of the review based on the inclusion and exclusion criteria described in Table 4.

In the second step of the selection process, 32 research articles that meet the inclusion and exclusion criteria are chosen for review documentation. It should be highlighted that these publications contain required information that broadens the scope of current research in WSNs.

3 | STUDY OF EFFICIENT RP IN WSNS

The main purpose of this research study is to analyze modern methods and techniques that improve route performance in WSNs in terms of energy efficiency, network life, and latency. The basic working principle in WSNs is communicating among heterogeneous devices and accumulating the collected data in the base station.

In the literature, various energy-saving measures have been used and studied. The following are some energy-saving techniques: We'll go over these methods in further detail now.

- Clustering
- Energy-efficient scheduling

- Energy-saving by directional antennae, etc.

Figure 3 shows how the routing protocol is classified in its most basic form.

3.1 | Network structure-based RP in WSNs

The network topology structure is critical in operating a protocol within a WSN.[19] In the in-network organization, node consistency is seen as a critical factor. The underlying phenomena studied in network structure are the way nodes in a network are connected and the process of communication and information sharing within the network architecture.

3.1.1 | Data-centric protocols

It is highly impossible to assign an identifier for every node within the network in the largest scale SN as many nodes are deployed in heterogeneous locations. In this scenario, it is impossible to identify a specific node in the context of the random deployment of nodes. Usually, communication of the data within the network occurs among the nodes where the absence of an identifier redundant data could be communicated over similar nodes, which causes a redundancy problem with a large amount of energy wastage.[20]

In addressing this problem, data-centric protocols have substituted traditional address-based RP in which the path establishment has taken place based on the node address.[21,22] Typically, in the central data center, the sink node within the network begins to communicate by sending a query to a selected location within the network. It awaits incoming information before it initiates data transmission among the nodes within the network. SP for information negotiation teams is considered the most popular data center protocol. The negotiation among the nodes is analyzed to mitigate the redundancy of the data and the energy consumption within the network. Several types of intermediate data protocols, including direct scattering,[23] roaming, gradient-based route,[24] and power-informed routing,[25] emerged from the advent of the research of various energy-efficient data-centric protocols.

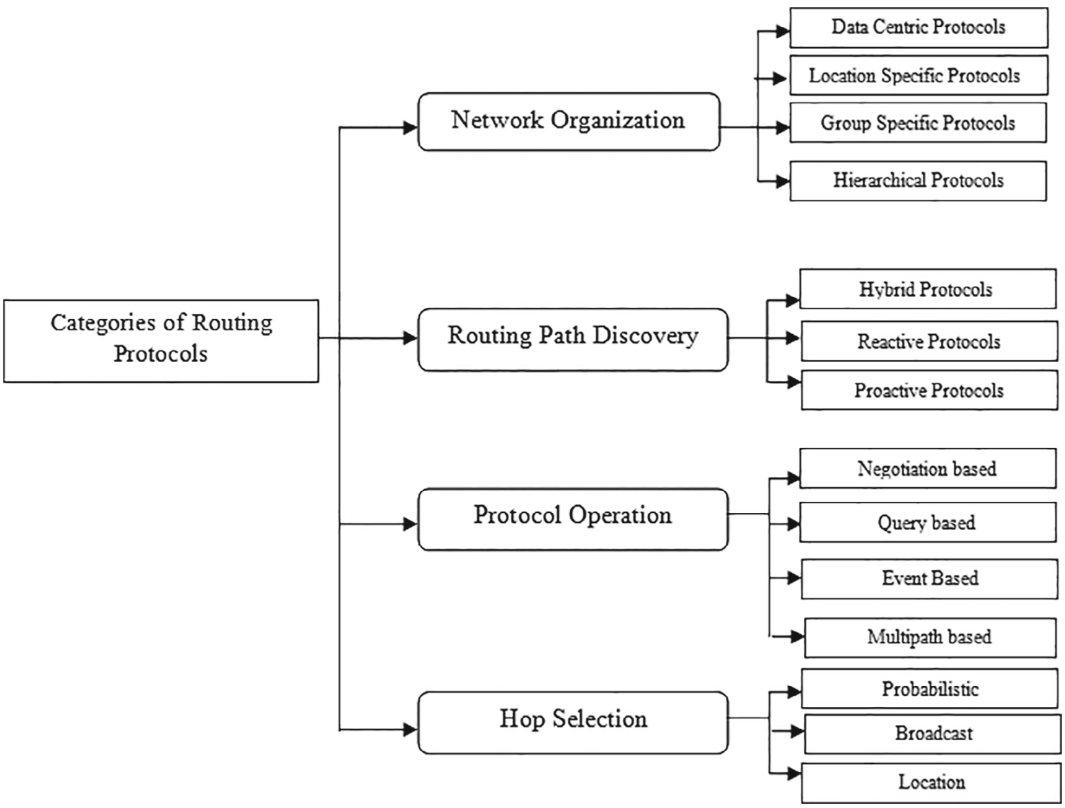

FIGURE 3 Outline of various RP in WSNs.

3.1.2 | Location-specific protocols

Within bigger-scale SN, basic RP is designed based on studying the distance I'm on nearby nodes. The other most important factor in LBR is the heterogeneous distribution of sensors within the network area. The underlying principle behind the LBR protocols involves basic tube assumptions in the first case; it assumes that each node within the network will have information regarding the neighboring node's position in the network topology. In the second case, if the position of the destination node is unknown, It is assumed to flood Hello messages to the neighboring nodes and identify the position of the neighboring know. This process is continued till the position of the destination node is identified.

The LBR protocol is generally tackled as the problem of identifying the position of the Centre Node within the network. These protocols are vital in healthcare technology monitoring and military tracking applications. In addressing this problem, several studies have developed protocols based on receiving the signal strength and global positioning system—the most popular LBR protocols including MECN[26] and GAF.

3.1.3 | Group-specific RP

Maintaining the location information of every node within the WSNs is considered a critical aspect when the size of the network dynamically increases with the deployment of a huge quantity of sensors. In this scenario, maintaining similar sensors within closer proximity in the form of groups is considered an appreciable solution. In the context of groups-based recruiting, the sensor is working on a similar kind of application or maintained within closer proximity to each other. These groups could work based on the type of application that significantly reduces energy consumption within the network. Several studies have understood the problem of group-specific routines in the context of monitoring. It was a genius location based on several energy-efficient algorithms studies indicated in Reference 27 that every SN is assigned to a specific group before deployment. In Reference 28, authors have projected a Group-Based Protocol for Large Wireless Ad Hoc and Sensor Networks (GBP-WAHSN) that may be redistributed inside the WSNs and impromptu networks. Further studies in Reference 29 have developed another variant of goods-specific routing protocol Group based on Mobile Agent Routing (GMAR) in specific data aggregation within each group using this protocol based on a mobile agent.

3.1.4 | Hierarchical RP (HRP)

HRPs are considered the most energy-efficient and intelligent protocols. In this context, the nodes with a sophisticated energy level are utilized in the initial cases to process the information within the network. In contrast, the nodes with lower energy levels are utilized for the sensing process. This type of protocol generally adopts a merging process in which the nodes are arranged in clusters so that each cluster has a cluster head based on its power level. These cluster heads are utilized for intense processing and communication within the network and base station. These protocols provide enhanced scalability and ensure no energy consumption and network longevity.

LEACH

Low-Energy Adaptive Clustering Hierarchy (LEACH)[30] is an individual of ultimate common SN sequences. The aim search uses local cluster heads in a way that decreases routers and group SN as clusters establish agreeable signal sizes. Only the aforementioned group heads, most importantly SN, will send data, that saves capacity. The total number of cluster heads is 5% of the total number of knots.

APTEEN and TEEN

Sensitive to the presence of a threshold, TEEN (Threshold sensitive Energy Efficient sensor Network) is a hierarchical protocol that responds to rapid changes in related variations such as temperature. Feedback is important for systems that are sensitive to the time when the network is running in restart mode. TEENAGERS use a data-based strategy that is consistent with segregation. The SN building is ensuing, accompanying abutting knots that form clusters, and this process repeats itself as far as the center of authority (fall) is attained.

The model, used in Reference 31, is proved in Figure 4. When clusters are settled, the cluster head classifies two thresholds to the knots. With visible qualities, there are strong and soft holes. A hard threshold is a very small annotation

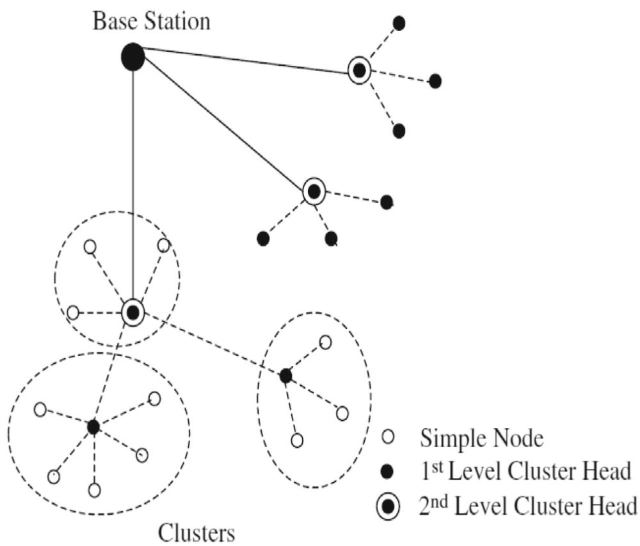

FIGURE 4 Hierarchical clustering of APTEEN and TEEN.

that will cause the SN transmitter to open and transmit data to the header group. As a result of a strong threshold, nodes can only transmit when sensitive material is within the range of interest, reducing the transmission value.

To control the number of transmissions, dense and flexible values can be adjusted. TEEN, on the other hand, is not suitable for applications that require periodic reporting because the user may not receive data if the parameters are not met.

The Adaptive Threshold Sensitive Energy Efficient SN code (APTEEN)[32] is a TEEN continuation that attempts to capture the opportunity data and responds to main opportunity occurrencesAPTEEN offers three types of queries: history, which analyzes past data values; one-time, which captures network coverage; and persistence, which traces the event over time. TEEN and APTEEN are more effective than LEACH in imitation. In conditions of capacity wantonness and endurance of the network, tests show that APTEEN does the same for LEACH and TEEN. TEEN gives excellent results because it reduces the transfer rate. Overhead and difficulty building collections at several levels, using limit-based tasks, and dealing with attribute-based questionnaires are key pillars of both approaches.

Several studies have proposed different clustering algorithms based on hierarchical routing, the most popular algorithm as shown in Table 5.

3.2 | Routing path discovery protocols

Initially, routing path discovery protocols are used to establish paths between nodes in WSNs These protocols have a big impact on the SN network longevity and energy efficiency. These protocols are classified into reactive, proactive, and hybrid based on the path establishment process.

3.2.1 | Reactive protocols

Information regarding the network topology and organization is not initially maintained in the context of reactive protocols. These protocols are activated based on the information request to dynamically establish a path among the sender and receiver nodes to initiate the communication. AODV and DSR are the most popular reactive protocols in WSNs.

3.2.2 | Proactive protocols

A table-compelled destroying contract is thought-out another name for full of enthusiasm RP. It maintains the information of various complete network topologies. It includes the predefined path between the various nodes in the SN, such

TABLE 5 Classification of energy-aware RP in WSN.

Protocol	Classification	State complexity	Mobility	Scalability	Power usage	Localization
MECN	*Location specific*	Low	Restricted	Minimum	Minimum	No
GAF	*Location specific*	Low	Restricted	Minimum	Restricted	Yes
GBP-WAHSN	*Group specific*	Moderate	No	Minimum	Not available	No
GMAR	*Group specific*	Moderate	Yes	Minimum	Not available	Yes
LEACH	Proactive/ Hierarchical	Cluster heads	Fixed base station	Good	Minimum	Yes
ELBSEP	Reactive/ Hierarchical	Cluster heads	Fixed base station	Good	Minimum	Yes
TEEN	Hierarchical	Cluster heads	No	Minimum	Minimum	No
APTEEN	Hierarchical	Cluster heads	No	Good	Maximum	Yes
SPIN	Flat/Negotiation/ Query based/ Multipath	Low	Restricted	Good	Minimum	No
REEM	Multipath	Low	Restricted	Minimum	Minimum	Yes
Z-SEP	Hybrid/Hierarchical	Cluster heads	Fixed base station	Good	Maximum	Yes

that it significantly reduces the congestion within the network. OLSR-Optimal link-state routing is the most popular algorithm under the proactive protocol.

3.2.3 | Hybrid protocols

Protocols are developed based on the combination of the merits included in proactive and reactive protocols. Link-state RP and Distance vector routing are considered the most popular RP.

3.3 | Routing based on the protocol operation

Several research studies show numerous efficient RP and algorithms based on the protocol's operational behavior over WSNs. The three major operation-based RP are negotiation, query, and multipath RP. In query-based RP, the sender initiates network contact, with communication between two nodes occurring only if the sender routes a query to the target node in the context of seeking specific information. According to simulation studies by several researchers, this procedure improves energy economy and decreases delay while improving performance.

3.3.1 | Negotiation based RP

To keep unwanted data transfers to a minimum in this protocol, the SN interacts with other nodes and shares their information about available resources and surrounding nodes. After the negotiation phase, the data transfer decisions are finalized.[33] example:

- SP for information via negotiation (SPAN), Sequential assignment routing (SAR).

3.3.2 | Query-based routing protocol

The receiver initiates the majority of these routing protocols. The sensor nodes will only provide data in response to the destination node's inquiries. The destination node sends an interesting query to the network to receive certain information. The target node senses the information, which sends it back to the node that originated the request. The following are some examples[33]:

- DD, COUGAR, SP for information via negotiation (SPIN).

3.3.3 | Multipath routing protocol

Multi-channel systems provide multiple options for data access, allowing load balancing, reduced latency, and better network performance. In the event of a road failure, most RPs offer alternatives. Multi-channel networks are more attractive than dense networks. The multi-route route does not save much energy as periodic messages have to be sent periodically to keep the routes alive. The following is the multipath RP[33]:

- SP for information via negotiation (SPIN), Multipath and Multi SPEED (MMSPEED).

In the case of negotiation-based RP, the transmission of redundant data is maintained at a minimum level. In this context, negotiation of the SN is initiated before data transmission in utilizing the available resources. Sequential assignment routing is considered the popular routing protocol that abides by the working principle of negotiation-based protocols.

4 | OPTIMIZED RP IN WSNS

Optimized routing algorithms enhance the protocol's performance in WSNs regarding network lifetime and energy efficiency and mitigate communication delay. Recent progress in designing such intelligent algorithms involves adopting machine learning and computational intelligence strategies as specified in.[34] Developing heuristic-based approaches in designing optimized clustering algorithms is considered an attractive area of research in recent studies. The main objective of this section is to analyze the adoption of various computational intelligence-based optimized RP in WSNs. Table 6 summarizes various Computational intelligence-based RP deployed in WSNs.

4.1 | Genetic algorithm based approaches

A genetic algorithm is one of the most prominent optimization algorithms devised based on intelligent biological search. The working principle involved in the genetic algorithm is to model the biological evolution of the data based on the fitness test conducted on the best population. In the context of genetic algorithms, the complete solution is represented in the form of a chromosome where the quality of execution of that particular chromosome is analyzed based on the fitness test where the concrete needs of the particular problem statement are extracted in an optimized manner. Recently several research studies have addressed the problem of energy-efficient routing within the WSNs to optimize the routing procedure built on the genetic algorithm approach.

TABLE 6 Genetic algorithm based optimization techniques in WSNs.

Author	Approach	Algorithm	Simulation environment	Performance metrics	Energy consumption
Bayrakli et al.[35]	Genetic algorithm	GABEEC algorithm	MS Visual C#	Network lifetime	Low
Jenn-Long Liu et al.[36]	Genetic algorithm	LEACH-GA algorithm	NS2	Network lifetime	High
Shamsul Wazed et al.[38]	Genetic algorithm	A Modified genetic algorithm for relay nodes	MATLAB	Network lifetime and data aggregation	Average
Sajid Hussain et al.[37]	Genetic algorithm	GA-based routing protocol	NS2 using 200 nodes	Network lifetime and data transmission	Average

The studies in Reference 35 illustrated a genetic algorithm-based approach named GABEEC (Genetic algorithm basic energy-efficient clusters in WSNs) to optimize the network's lifetime. The implementation details of this approach include two phases of execution: in the first, clusters are created and do not change over the network's lifetime, and in the second, communication between cluster heads is initiated using time division multiple access protocols, with data transmission organized by time slots. The major goal of this strategy is to optimize network longevity. The fitness function comprises three parameters that reflect the time slot a node in the network has expired. The imitation results show that the projected GABEEC code outperforms the LEACH plan all along the unending data collection.

In their research studies, Jen-long Liu et al.[36] developed an adaptive clustering protocol addressing energy efficiencies in WSNs. The major goal of this research is to extend the network lifetime of WSNs. The study's main idea is to integrate a genetic algorithm with the LEACH protocol. The primary difference in the suggested approach is that it includes a preparation phase before starting the setup and steady-state phases. The cluster head is elected during the preparation phase based on the efficiency of the cluster's nodes, and this process is repeated recursively at the start of each phase. The construction of a pseudo-code for the proposed LEACH-GA protocol is included in the implementation details, as is the deployment of the suggested technique in a homogeneous sensor environment to test it.

Shamsul Wazed et al., have developed a genetic algorithm-based approach that schedules the gathering of the data over the network that simultaneously enhances the network lifetime. The evaluation of the proposed mechanism is analyzed both in the context of a smaller WSN environment as well as the larger SN environment. It is evidenced that the network's lifetime is slightly enhanced compared to traditional mechanisms. Sajid Hussain et al. presented their work based on addressing the data transmission rate, wherewith in his work, a detailed illustration of the genetic algorithm-based protocol is devised and implemented.

4.2 | Ant colony optimization-based techniques in WSNs

The ant colony optimization (ACO) algorithm is a metaheuristic algorithm for solving combinatorial problems that are inspired by nature.[39] The main idea behind ACO is to think of the problem as a search space and generate the best search path using pheromone communication. In terms of optimization, it might be considered one of the greatest graph-based metaheuristic algorithms. Several studies have focused on the development of energy-efficient and performance-centric algorithms for use in WSNs. Wang et al.[40] developed an energy-aware optimization approach based on ACO that could be adaptive and dynamic to the changes that occur in WSNs. In this approach, an ACK-based mechanism is developed through which the nodes dynamically join the cluster based on cluster head acknowledgment. Additionally, it includes the feature of inter-cluster communication based on the ameliorated feature of ACO. Further studies in Reference 41 proposed a clustering approach based on ACO where the cluster head election plays a vital role in the study.

Several studies in References 42,43 have enhanced the existing protocols like LEACH and Multipath routing in the context of WSNs. It is observed that these comprehensive approaches are very dynamic and adaptive such that in the context of ACA-LEACH, the network lifetime is enhanced. It provides inter-cluster communication. It also provides the energy value comparison among the nodes involved in the WSNs. In the case of enhanced Multipath routing, seamless data transmission is enabled over the network that could dynamically construct multiple paths based on the requirement. It enhances the network lie time.[44]

4.3 | Energy optimization techniques for WSNs

Wang et al.[45] use a portable sink to create a composite method based on particle mixing. To achieve energy efficiency, EPMS uses visual integration and Particle Swarm Optimization (PSO) in combination. The visual integration method raises information about the location of the node and the residual power parameters of the SNs to detect CH. The EPMS router describes three types of data packets: hi small, communication pack, and communication pack-h. Finally, the message whole is used to please data to the decrease node. Imitation results show that capacity devouring across the network has been discontinued by as well as 12%, superior to a more protracted network existence than LEACH and TTDD. On the other hand, the shake levels and end-to-end delays are kind of revised.

The Artificial Fish Swarm Method (AFSA) was developed by Helmy et al.[46] as an SI-based hierarchical routing algorithm to reduce power consumption and improve network life. This method selects the best CH by combining Preying, Swarming, and Tracking. Based on professional behavior, fitness work selects the best CH. The simulation result in

MATLAB shows that the process works much better than LEACH and PSO. Liu et al.[47] introduced Quality of Service (QoS)-PSO, an algorithm based on the QoS agent. This solution uses a QoS performance, and a flexible configurable PSO algorithm to improve overall network performance Network traffic flow, route rank of each node, and changes in the network study of land were all resolved by knowledgeable operating system manipulators. These negotiators were administrative of the network and routes. QoS-PSO protocol has better QoS rates for packet delay and loss compared to AODV and EEABR. The protocol is best calculated on large networks in terms of size. A major router acquisition, on the other hand, adds a network control package over it.

Kuila and Jana[48] have solved two well-known problems of efficient use: energy efficiency and integration. The authors have used the PSO method to create linear and indirect line formation for these two major problems of efficiency. If you use a particle coding system that works well with the multiobjective compatibility function, the weighted method is best suited for route and integration solutions. Between delays in sending data packets and transmission distance, route transactions are created. The PSO-based optimization algorithm finds the shortest route and has the least data going from all the gates to the base station. The coding strategy and multi-purpose suitability function are used in the weighted method approach. Concerning the total data transferred to BS, network life, and inactive SNs, the law exceeds the GAR and MHRM principles. The well-known RP of WSNs which is important for energy efficiency measures will be included in this section. Table 7 compares power monitoring methods using different parameters.

Power consumption is a very important factor in WSN. RP handles issues such as energy efficiency and service quality (QoS). To maximize network performance, the Dynamic Source Routing (DSR) protocol uses a sleep/wake planning method. As a result, less energy is used. However, it also increases the amount of time spent waiting. Brar et al.[49] developed a PEGASIS-DSR optimized routing protocol (PDORP), a dynamic tracking system with direct transmission. This legal process, which combines both your DSR and PEGASIS RP features, was created by combining Bacterial Foraging Optimization (BFO) with GA to determine the best route channel. The sensor nodes are randomly programmed, and the distance between each node and its neighbors is measured and compared to the threshold value. From a large set of nodes, the route finder selects the best route. PDORP utilizes the active and passive features of the route concept. To bring improved QoS and longer network life, a different integration method is used. PDORP uses a combination of BFO and GA signals to achieve higher QoS and longer network life. WSNs are used in a variety of applications, each with its own set of conditions. However, we can assume that the WSNs that we are directing are delayed, where energy-saving measures can be applied to almost every layer of this protocol stack, including MAC, route, and system levels. As a result, we feel that a protocol stack, or set of protocols, is essential to provide energy-efficient data exchange.

On the other hand, the trade-off between energy consumption and delay is an essential issue. However, it is impossible to consider all the perspectives in the design of protocols, so the problems are still like many discussions in numerous literature. The protocol design depends on a specific application field with clear characteristic requirements since it would be more complicated to design a protocol to generalize to all the fields except you are designing a protocol framework.

4.4 | ML approaches in WSNs

ML is the process in which learning from experience and study is considered the major phenomenon that mitigates the burden of explicit programming of every task. Computational intelligence techniques attract many researchers with their efficient and cost-effective performance. Furthermore, these techniques have the capability of analyzing complex data. Recent studies in solving various problems in WSNs are included in.[50] The application of ML-based approaches reduces human intervention in the context of reprogramming when changes occur dynamically within WSN. Recent advances include the development of effective ML-based algorithms and techniques for solving key challenges like coverage and connectivity, fault detection routing, and data aggregation within WSNs. Table 8 includes a summary of various techniques developed for addressing WSNs.

4.5 | Parameters to consider for WSNs energy optimization

We can forecast the energy the SN will have at any given time. In other words, we can use a regression model to predict how much energy a sensor's battery will have over the following several hours or days.

The following are the parameters that come to mind.

TABLE 7 Various energy-aware RP are constraints comparison.

Protocols/Parameters			MAC Protocol	Reliability	Adaptability	Delay predictability	Collision avoidance	Energy consideration
Contention-based	Sender-initiated	Single channel	MACAW	Achieved by sharing within nodes	Yes	Competent than MACA	-	-
			MACA	Unidirectional delivery	Yes	Few efficient	-	-
			FAMA	-	Yes	-	-	-
		Multi channel	S-MAC	-	No	Yes	Yes	-
			PAMAS	-	-	Yes	-	-
			ICSMA	-	Yes	-	-	-
	Receiver-initiated	MARCH		-	-	Yes	-	No
		MACA-BI		-	-	Yes	-	Yes
Reservation	Asynchronous	Dominated- awake		-	-	Yes	Yes	-
		Periodically- fully-awake		-	-	Yes	Yes	-
		Quorum-based		-	-	Yes	Yes	-
	Synchronous	DCF		-	-	-	Yes	-
		DPSM		-	-	-	Yes	-
		HRMA		-	-	Yes	-	-
Scheduling mechanisms	DWOP			-	-	-	-	Yes
	ER-MAC			-	-	-	-	Yes
MAC	RBAR			-	Yes	-	No	-
	BAMAC			-	-	-	-	Yes

TABLE 8 Analysis of various ML approaches developed for WSNs.

Author	ML approach	Challenge addressed	Environment	Complexity	Observation
H. Chen et al.[50]	Reinforcement learning	Coverage	Distributed	Low	Enhanced network lifetime
B. Yang et al.[51]	Bayesian	Coverage	Distributed	Moderate	Minimized complexity of computation in WSN
J. Shu et al.[52]	SVM + Decision Tree	Connectivity	Centralized	High	Enhanced network lifetime
P. Gil et al.[53]	SVM + PCA	Fault detection (outlier analysis)	Distributed	Moderate	Enhanced accuracy
S. Shamshirband et al.[54]	Q-learning	Fault detection (DoS)	Distributed	High	Enhanced network lifetime
S. A. Haque et al.[55]	Regression	Fault detection	Centralized	High	Enhanced accuracy
S. W. Awan et al.[56]	Hierarchical clustering	Energy harvesting	Distributed	Low	Enhanced energy efficiency
F. Chen et al.[57]	Deep learning	Energy harvesting	Centralized	High	Enhanced energy efficiency
E.K. Lee et al.[58]	Reinforcement learning	Energy harvesting	Centralized	Low	Enhanced energy efficiency

- Battery voltages Low (L) volt and High (H) volt.
- L current and H current in the circuit.
- Rate of energy consumption.
- Humidity, temperature, and altitude in the environment.
- Battery discharge cycle.
- The size of the solar panels and the LUX, current, and voltage.

In general, there are many considered costs while evaluating any routing protocol.

- delay on each link, so we have to find the route minimizing the delay between the source and the destination node.
- cost of each link, so we have to find the route minimizing the cost between the source and the destination node.
- flow, on each link, we have to find the route minimizing the total flow between the source and the destination node.
- distance, so we must find the route minimizing the distance between the source and the destination node. The best route is the one leading to the least distance value.

In some cases, we can take into account a combination of criteria.

For example, if we consider minimizing the delay while routing (forwarding) a message using high-degree nodes. So, we have to minimize the term (D/degree). The energy consumption of WSNs is influenced by various elements, including sensor position, cluster inter-sensor distance, channel estimate energy, power circuit, channel loss, mobility factor, and residual energy.[59]

SN is not the same as a network built into the infrastructure. As mentioned earlier, a device in such a network always has a device. This is an important factor in the development of a low-power MAC protocol. SN uses a variety of techniques and requirements depending on the application. One of the most important ways of SN is to raise awareness about the application. As a result, MAC protocol must be flexible enough to meet the needs of individual application areas while still operating efficiently.

FLEOR[60] is an FL-power-based route protocol aimed at improving network life by increasing power efficiency and power balance between SNS. It is a multiobjective algorithm for the process that considers the Distributed Clock Synchronization Protocol (DCSP) and the Node Interference in addition to the direct input of energy balance, level to sink are also indistinguishable from energy efficiency. In the SEPFL[61] the CH selection procedure is shifted to the SEP[62] to increase network duration. This is achieved by combining unconventional thinking with the common CH election, values utilized in SEP. The abstract thinking system takes into account node strength, as a modification of the abstract input in the CH option, level of the battery, distance to BS, and node congestion.

As a result, the incomprehensible inference system combines two distinct possibilities for selecting the most suitable SN as CH. The first probability is found in the variation of the intangible input based on the ambiguous legal basis, and the second is calculated with the use of threshold values, the weighted probability is then examined by determining the definitions of both probabilities, with the node with the highest probability being chosen as CH. Imitation of the data suggests that the SEPFL has improved significantly over the network's lifetime, with 73.2 percent and 42.4 percent, respectively on exits at 68.54 and 33.4 percent. Although the SEPFL extends the life of the SEP network by modifying the power consumption within the SN, it does not include many channels in its core functionality, which may interfere with network efficiency.

NORIA[63] is an intelligent route algorithm based on the relay node assignment network that incorporates abstract thinking in the path of the route decision. The unconventional thinking system of the proposed system uses the route length and battery level as a variant of the inconsistent inputs in the decision-making process, so an area with very few hops goes to the immersion area, and the highest level of the battery is selected as the route, which combines data from it. neighbors and send it to the sink. The FL machine in NORIA reduces the number of router acquisition packages and router gates while reducing route configuration time, making the projected contract trustworthy and acceptable for compact WSN, contingent upon the imitation results. In addition, the function shift process in NORIA guarantees load adjustment and avoids network node breakdown. Apart from this, it counts and controls more when making route decisions. FMOLD[64] is a multi-objective fuzzy online tracking algorithm that aims to maximize network life while minimizing transmission delays. It determines the best way of measuring two opposing goals: reducing source latency to sinking and increasing network life. By defining an unambiguous-participation function for each objective and judging a multi-purpose enrollment function by joining individual aims utilizing the Ordered Fuzzy Averaging (OFA) controller. This transaction can be achieved.

FEQRP[65] uses a nonlinear setting method to maximize network life and achieve a balanced power load within the SN. Its functions are divided into three categories. The source area finds all its neighbors and calculates their distance from the sinking area in the first section. Then trace a set of node candidates near the sink. The source area then calculates the boundary strength of the candidate and asserts a satisfactory set of growth accompanying equal or better substance at opening strength. In the last step, the beginning region increases RE and distance to the locale to reckon the pressure of each satisfactory node. FEQRP effectively balances the load capacity between SNs while avoiding network fragmentation, which reduces latency and performance of packet loss, depending on the simulation results. However, it does not support the value of a package or multi-route route. FROMS[66] is a dynamic multidisciplinary channel protocol that has a modified response strategy to improve multi-channel networks. This is achieved by defining many sink optimization problems as a learning challenge to strengthen and use the Q-learning algorithm to improve power use while exciting data packets to various sinks. The code administration arrangement is established in the Steiner Tree, place the ideas communication feature is used to transfer position facts between adjacent growth.

QELAR[67] is an RL-based, energy-efficient, distributed RL system based on RW. It extends the life of the network by dissolving the power consumption. The proposed QELAR protocol learning method is based on the Q treasure, at which point the wonted transmitter calculates the relative principles of each neighbor. It checks the RE and the power distribution between a set of nodes, these q values establish the expected reward, and the most rewarding area is selected as the next transmitter. According to simulation studies, the Q-learning algorithm in the QELAR protocol improves robustness and flexibility in changing network topologies while minimizing network overhead and power consumption.

In addition, as the number of agents grows, the Q-knowledge treasure considerably increases the calculating complicatedness of the QELAR code. FTIEE[68] is a bright route of WSNs categorization that includes a healthy knowledge way of persuasive data courses. Using a delivered education form, each sensor node creates route conclusions alone, by selecting the appropriate neighbor node or properly as a CH data transfer law. The projected pattern uses the Q study plan to decide the reward function of selecting the next neighbor node, premeditated utilizing two limits: a) distance betwixt sensor node and BS; and b) the RE node. For data transfer, the district accompanying the best q advantage is picked as the next neighbor node. As a result, during a good choice of CH, the route line between the clusters is automatically read, reducing the overheads required to build a route.

MRL-QRP[69] is a multidisciplinary RL-based protocol that supports very active WSNs. It established the Distributed Value Function Distributed Reinforcement Learning (DVF-DRL) invention, which admits cooperation between SNs in selecting the appropriate QoS system. In DVF-DRL, when the sensor node sends a data bundle, it resolves the accomplishment of QoS itself allures the next neighbors, and raises reward accomplishment through worldwide cooperation. The reward function of the MRL-QRP contract is established by the ACK motor, which resolves link value or q profit contingent upon the delay and small transfer rate. It meets the QNS necessities of SN by transferring packets to the atmosphere at a very extreme Q price. It achieves all-encompassing growth by communicating local network facts and ranking news inside the SN. Imitation results signify that the self-centered policy in the MRL-QRP shows important improvements in late-to-end broadcast delays and bundle childbirth rates in well-active atmospheres. However, it does not involve RE-node as route versification to select the correct course. In WBANs, RL-QRP[70] is an RL-located QoS code. It uses a delivered Q-knowledge invention to select the appropriate pattern at which point each sensor node resolves a small transmittal rate and E2E delays as link feature signs. After exciting the data whole, the adjacent knots reward it accompanying certain or negative rewards. The q-profit guide the sensor node is restored on two together the reward and the supposed future reward, which is used to create future judgments of the appropriate alternative.

In addition, the flexibility of the protocol in highly variable traffic is due to its flexibility. Compared to the QoS-AODV protocol, the imitation results show a meaningful rate of small deficit and moderate E2E decline, especially in extreme traffic environments. This study, still established Independent Distributed Reinforcement Learning (India), which does not specify effectiveness in general and is only appropriate for limited networks.

For WSNs, EQR-RL[71] is an RP-based QoS algorithm that derives RL-based power. It is a dual-phase two-algorithm that works in two ways. Each sensor node uses RL to discover network competencies in the first stage, even though it has no forethought. Each node uses a data pack plunge, that holds a neighbor ID, timestamp, E2E delay, number of packets moved, and RE, to correct districts familiar with the routing table utilizing the flood control pattern. The sensor node before using load compares to spread data traffic book established any of QoS determinants to degree delays, jump on one leg counts, and route distance. When a node sustains a data bundle, it compares the QoS limits accompanying the router table recommendation and before uses the wheel of the chance process to select the next spring node. EQR-RL protocol rating improves network density and packet delivery rate significantly, depending on the simulation data. The EQR-flooding RL strategy manages node failures and network traffic but requires the use of high bandwidth. EEABR[72] is an ACO-based energy-saving algorithm aimed at extending network life. In the EEABR, each area produces a forward anchor that always contains the address of the most recently visited ants for better use of power and distance. The MRP-ACO contract[42] connects responsive unification accompanying diversified network continuations. The MRP-ACO unification treasure is the main control invention at which point BS controls the choice of CH established signal substance and RE SN. Authors have constructed capacity-located requirement work to favorably transfer SNs to CHs. The MRP-ACO obligation, in another way, uses ingenious follow-evident ants to look for the ultimate correct routes from the beginning to the goal.

LTAWSN[73] is a life-saving technique that uses the ant's ingenious features to lower the strength devouring of the knots. This is realized by mixing local appearance into the next-bounce node option function. The two strength steps in the task space produce raised excuses to the extreme capacity node and guarantee load balance betwixt SNs. Once the ants have attained their goal, they resume the ants and cautiously review the aroma aggregation in course contingent upon the strength devouring and estimation of spring in the decrease node. The simulation results show that LTAWSN significantly improves power economy and long network life while achieving limited data transfer across SN. However, it leads to a greater path and more control. ACOEA[74] is an advanced ACO-based multipath algorithm that extends network life. The converted ACO looks at the angles and distances between the nodes to produce multiple paths to the sink. The angle determinant between the beginning node, the communicated node, and the absorption node is used to develop the chances of a change in the treasure to the ACO treasure, which admits route bounce counts expected upgraded.

In addition, ACOEA distributes repair ants to increase network connectivity by placing RE under certain road boundaries with high power nodes. The imitation results show the adeptness of the ACOEA treasure in the protocol of several live growths, capacity devouring, and load weight distinguished from the standard multipath RP. However, it does not count power consumption due to the re-transfer of data packets under changing network conditions.

ACOWMSN[75] is an ACO-located QOS router treasure that inquires about the high-quality habit of meeting use-distinguishing QoS guidelines while reaching the network existence period. It is an active route protocol that considers many QoS conditions, such as delays, power, bandwidth, and packet loss, choosing the shorter route from the source to the area with the lowest cost of the route. Create an effective approach using two types of artificial powers: forward ants and late ants. To find the right goal for the marked goal, forward ants maintain network rank news to a degree of leftover capacity, increasing line delays, and small misfortune rates. Medium growth that meets QoS necessities will be picked as the next terminal for ants. Forward ants fit ants that return and continue the beginning district side-by-side but in the opposite course later arriving at their aims. Based on expressway character and forthcoming-term delays, these ants secretly cautiously review the aroma aggregation of each node bothered on the trail. Imitation verdicts show a meaningful increase in endurance and adaptability in changeful network topologies while lowering the moment of truth and strength devouring. However, it is not appropriate for abundant networks on account of the extreme control and sluggish level of unification.

To use two together combined use of several media and scalar data loads on WSNs, EAQHSeN[76] is a router pact that sees QoS accompanying a leading ACO-located treasure. It can control differing QoS limits that guide miscellaneous traffic, to a degree combined use of several media and scalar SN. This is attained by trying any routes for various types of data traffic loads. EAQHSeN contract uses leftover frequency range and E2E delays as wondering looks for selecting the next leap node for combined use of several media data transfers. AntSensNet[77] satisfies the QoS requirements of WMSN by integrating consecutive configurations with an ACO-based route. It is a multidisciplinary approach that considers the functional and functional components in the development of a route. It supports the miscellaneous combined use of several media traffic classes, each accompanying allure's own set of QoS steps. This is attained by asking for a packed schedule procedure that considers the key arrangement of each traffic time and decides on diversified habits to appease the QoS necessities of the scheme, to degree delays, leftover capacity, and small deficits. It likewise presents a productive multipath program bundle treasure for lowering blockage in the program bundle broadcast. The design of the AntSensNet pact divisions reduces data transfer conflicts middle from two points appendage knots and increases strength adeptness and abeyance. Compared to the standard AODV contract for various traffic loads, imitation results show important improvements in transfer rate, strength adeptness, and E2E delays. Despite this, it constitutes a sort of control pack (FANT, BANT), data packs (DANT), program (VFANT, VBANT), and unification (MANT), chief to raised route overheads and complicatedness. The IEEABR code[78] cultivates a restlessness ant-EEABR route that aims to correct strength adeptness in a pliable background. This is reached by utilizing SN's free capacity and the use of highway capacity as route versification to decide best practices.

EAMR[79] is based on ACO, an energy-efficient route-enhancing system with WSNs that are delayed through the intelligent search for real ants. It is a mixed-route strategy that captures the reaction time to create a route and an active eye during route adjustment. By spreading the ants forward, the source area develops multiple paths in the beginning. When the front ants reach their goal, they switch back to the ant's recompensing. The latest completely amends the aroma aggregation in the flow course established strength devouring, leftover strength, leap counts in the decrease node, and route congestion. Load balancing is achieved by this method of pheromone regeneration, which distributes traffic between several routes based on the quality of the proposed method. Additionally, the EAMR algorithm may recover from link failure due to high data traffic or high-node traffic. The EAMR protocol violates the AOMDV and EEABR protocols according to the E2E duration and delivery rate, according to the complete copying of the authors. However, it has more to say about route and control. IACO-MS[80] is an ACO-based advanced algorithm that integrates integration technology with a mobile sink to overcome the problem of a hot static network. Calculates optimal data collection for mobile sinks based on the distance middle from two points CH and the distance to different movable sinks.

The curious determinant rate reduces broadcast delays and the persuasive use of CH. It increases search capacity in general and speeds up the union. Imitation results show meaningful improvement in network existence, capacity adeptness, and broadcast delays distinguished to ACO-M router treasure. The IACO-MS treasure cannot accomplish link defeats on account of link activity. In the WSN-located group, Kuila and Jana[48] popularized a PSO-located strength-conditional route protocol. By utilizing an adept piece encrypting system, the projected code addresses two unification and refining issues at WSN. To obtain maximum network growth and depressed capacity devouring, the projected contract unification approach has grown as Non-Linear Programming (NLP). To balance the capacity use of all CH, ultimately CHs second-hand as new-spring transmit data transfer knots grant permission to have middling appendage growth. However, the projected protocol route is delineated as a Linear Programming (LP) question, that increases the profession between two rhythmical versifications: broadcast distance and hops computation, in an attempt to select an acceptable transfer part inside the broadcast distance. Under a bendable network makeup, imitation results display that the projected code betters network history, network coverage, and packet delivery rate significantly. Although load balancing extends the life span of CH, long connections deplete SN power far from CH, making the network inoperable.

TPSO-CR[81] is a two-phase protocol based on PSO for merging and extraction of wireless SN. The authors introduced a series of systems in their proposed TPSO-CR protocol to address the concerns associated with the route. The PSO-based clustering algorithm selects the best CH for power efficiency, package acceptance rate, network coverage, and collection connection quality. In addition, it improves network robustness and resource utilization. On the other hand, the PSO-located crushing treasure constructs a new practicability function that trades middle from two points capacity effectiveness and network relates (RSSI) to decide the appropriate routes from CHs to BS. The projected TPSO-CR contract keeps in conditions of calculation, transfer rate, capacity devouring, and network establishment, contingent upon the imitation results. Apart from this, the TPSO-CR obligation has long broadcast delays as the MAC coating of each node stores the packets before changing bureaucracy to the next spring node. At WSN, the PSO-ECHS[82] algorithm is based on the PSO, an energy-efficient CH algorithm. Developed the appropriate CH option by designing particle code schemes that work well with the fitness novel function that takes into account residual strength, immersion distance, and the inside range of the collection.

In addition, the PSO-ECHS collection process for the weight algorithm improves network efficiency. Connecting the SN to them is reached by seeing the leftover CH capacity, position news, and node titles. When BS is concurrent with an activity in the audio-visual field, imitation results signify that the projected PSO-ECHS algorithms act better in conditions of strength effectiveness and the number of live knots. When the BS district changes from the center to the corner of the neurological field, however, the lifetime of the network is reduced. This is because it does not consider a multi-hop data transfer algorithm. In addition, they do not evenly distribute CH everywhere, which can result in unbalanced energy consumption.

QoS-PSO[83] is an agent-assisted, QoS-knowledgeable route obligation that uses PSO's wise search facilities to transfer QoS-distinguishing uses. The QoS-PSO treasure uses QoS depiction as a function to select the right arrangement, which involves sure determinants in the way that delays, frequency range, and small misfortune. Intelligent search powers QoS-PSO treasure can accustom to changes in a network the earth's features and node route rank. These powers are the reason for confirming and claiming the way to the decrease node. In the protocol of delays, bundle deficit, and QoS act, the maintenance of the imitation displays that the QoS PSO means surpasses AODV. However, it does not allow for the possibility of the RE's neurological node when making route conclusions, which can bring about belief in divinity devouring.[47] projected a PSO-located unification pattern accompanying a traveling decrease named EPMS to address the spring district question in the standing WSN. The EPMS treasure integrates movable sinks accompanying in essence unification forms to weaken abeyance and longer network history. With a better choice of CH, the ability to be seen with eyes unification of the EPMS invention allows for the possibility of RE and node rank. The movable decrease delivers Hello packets to CHs for the data group afterward group. CH accompanying the maximal RE in the allure ideas range is picked for data transfer. While embellishing network growth, mimic gains display an important decline in capacity use and broadcast delays. The projected route contract mistake fortitude restores network relatedness by verdict a destroyed way, resulting in high throughput. FABC[45] is a hybrid combination that attempts to increase its convergence rate by combining ABC efficiency with fractional calculation. The authors use the FABC method to develop a new eligibility function for the appropriate CH choice in the proposed route algorithm, taking into account many test features, such as power consumption, distance, and delay.

Ordinary ABC has the potential to be trapped in a fast-paced environment and may produce poorly prepared results in certain areas. To overcome the problem of premature integration of the ABC algorithm,[84] incorporated the idea of quantity forethought in existent ABC chief to the happening of a singular wit invention named Quantum ABC (QABC). This refurbished QABC invention reinforces the all-encompassing search proficiency at a logical level of protocol and applies the appropriate CH choice to the projected contract. Correct CHs are picked by determining the distance between the node and the CH, the leftover capacity of the node, the position of the node, and the network construction. In addition, the projected unification pact favorably joins the accompanying network study of land and balances network load betwixt picked CHs. Experimental judgments desire that the projected route pact established by the QABC invention considerably reduces route delays and capacity devouring while asserting good probable cohesion and network dependability. However, the principal unification policy of the QABC-located unification invention demands a BS rich in possessions and adequate supplies and efficiencies. The BeeSensor[85] is a strong, adept, occurrence-compelled, and climbable WSN structure system.

The Be Sensor-C[86] is a multi-dimensional, energy-efficient, driven event system developed in the previous BeeSensor protocol by integrating a powerful integration method. For the best CH choice, this event-based compilation method puts a new agent named HiveHeader in each beehive. A node with a high RE and closeness to the occurrence sends HiveHeader first and has an extreme chance of being a CH node. By learning the abstinence from food practices of the affected honey-making community, the ABC-SD protocol[87] handles two complicating and course issues in WSN. The ABC-SD contract unification treasure is a principal control invention at which point BS controls the CH choice by imposing upon the interplay between the status of ideas and the use of cluster capacity. As a result, the authors built a multiobjective appropriateness work that established burden forethoughts to efficiently transfer SNs to CHs. In addition, the ABC-SD obligation route is a delivered action that builds valuable movements through the adjustment between strength adeptness and leap forecast in route pick.

In addition, the flood control system of the ABC-SD contract considerably reduces overheads. GAR[88] is a GA-located route-conditional electronics. Reducing the distance between the transmitting node and the center of authority advances strength effectiveness. After accumulating all the data packets in the beginning growth, GAR applies the data accumulation to the transfer growth. These transmit growth lower lacking data and routes to BS by merging and multi-bounce ideas. GAEEC[89] is a depressed-strength compound that uses GA to double the growth of WSN. The authors categorized the network into an appropriate number of upright clusters and established the distance from the absorption section to the first GA. After standing clusters have been designed, GA is used to select the highest-in-rank CH for each cluster by conceiving a new appropriateness project.

The GADA-LEACH obligation[90] uses GA to reduce the CH option process of the current LEACH process. This is completed by shrewd the worth of each node utilizing determinants to a degree RE, the distance middle from two points CH and connected knots, and the distance middle from two points CH and BS. For Wireless Networks,[91] proposed a multi-objective QoS (WMNs) implementation strategy. The proposed method combines MNSGA-II with the analytic hierarchy (AHS) system to select the appropriate transmission method. The MNSGA-II invention reinforces the existent NSGA-II treasure by assembling the best choice Pareto answers utilizing the Dynamic Crowding Distance (DCD) procedure. The suggested method turns the multiconstrained QoS router problem into a multi-purpose route and uses a pre-based codec to find a few correct routes between source and destination. It measures the connection of the sensor node by checking the status of the link according to the Expected Transmission Count (ETX). In addition, in the case of a high-traffic mode, the proposed method eliminates the need for repair work to replace damaged routes and eliminates the duplication of nodes in the destination. The authors show that the proposed method exceeds the R-NSGA algorithm in terms of throughput and transmission latency under various network and node traffic using a wide range of simulations. The proposed MNSGA-II approach enhances the computing complexity of the routing protocol and communication override.[92] introduced the Multiobjective Genetic Algorithm-based energy-efficient QoS-aware aware algorithm (MOGA). Configures multiple QoS metrics to establish application-specific methods for sink nodes, including delays, bandwidth, and power consumption. It creates a second objective function to address this question by combining several branches of the learning question by admitting undertakings betwixt two goals, QoS limits, and capacity use. To form the first set of route timbers, the Depth-First search (DFS) invention is used to find all the alive routes. Each line calculates the fitness profit utilizing the fitness function of each duplication. Cross-connecting hereditary functions reinvigorate chromosomes (routes) and advance the QoS request-particular characteristics of trails. The multi-item trading system greatly extends the life of the network, depending on the simulation data. MOGA, on the other hand, is looking to Pareto for appropriate answers and requires a high density of solutions in the search field.

In the combined WSNs,[93] developed a cost-effective QoS destroying protocol that established a non-dominated sorting genetic algorithm (NSGA-II). In two-state WSNs, a big-league sensor node that answers QoS-particular use limits to a degree of E2E delays, capacity devouring, and dependability through crossover and change function is picked as CH, that transmits joined data to the fall node. It is a multi-purpose addition that specifies various appropriateness acts for each aim and optimizes each QoS limit to suit use necessities. In addition, it guarantees the one correct answer in the search region is not partial toward additional appropriate resolutions. Consistent accompanying the results of imitation, the projected pact established the NSGA-II treasure everything best in growing the number of QoS verification and capacity use. The NSGA-II treasure, in another way, demands a very long time to produce identically scattered resolutions.[94] is a Distributed Genetic Algorithm (DGA) located in multi-forced QoS. It is a composite route pact that uses the AODV alive route and DGS alive route. In exchange for Route Request Routes (RREQ) and Route Response (RREP) ideas, AODV builds a route between source and location. The active process uses the DGA algorithm, in which the primary channel produces GA packets. Each sensor area creates a fitness value g after receiving a GA (vi) package. The taxonomy of computational intelligence techniques based on RP is mentioned below in Table 9.

Many other design and deployment criteria influence energy-saving methods. These elements are critical and impact the overall operation of a MAC protocol. The following are some things to think about while creating energy-efficient MAC protocols: network topology, deployment strategy, antenna mode, regulating mechanisms, latency, throughput, QoS needs, and some communication channels. CI techniques are mentioned in Table 10.

In Reference 95, the authors provided the first study of bicriteria routing games, where the players attempt to simultaneously optimize two parameters: their path congestion and path lengths. The motivation is the existence of efficient packet scheduling algorithms which deliver the packets in time proportional to the social cost. The results proved that quality of routing (QoR) games stabilize and their equilibria provide good approximations to the Congestion and Dilation optimization problems. In Reference 96, authors proposed a new optimization algorithm with low complexity and high parallelism. To validate and evaluate the proposed models and algorithm, they applied the optimization to the minimal

TABLE 9 Taxonomy of computational intelligence-based RP.

	Energy-efficient	QoS-aware	QoS-enabled and energy-efficient
Fuzzy logic (FL)	FLEOR,[60] SEPFL[61,62] NORIA[63]		FMOLD,[64] FEQRP[65]
Reinforcement learning (RL)	FROMS,[66] QELAR,[67] FTIEE[68]	MRL-QRP[69]	RL-QRP,[70] EQR-RL[71]
Ant colony optimization (ACO)	EEABR,[72] MRP-ACO,[42] LTAWSN,[73] ACOEA[74]	ACOWMSN,[75] EAQHSeN[76]	AntSensNet,[77] IEEABR,[78] EAMR,[79] IACO-MS[80]
Particle swarm optimization (PSO)	Kuila and Jana,[48] TPSO-CR,[81] PSO-ECHS[82]	QoS-PSO[83]	EPMS[47]
Artificial bee colony (ABC) optimization	FABC,[45] QABC[84]		BeeSensor,[85] BeeSensor-C,[86] ABC-SD[87]
Genetic algorithm (GA)	GAR,[88] GAEEC,[89] GADA-LEACH[90,91]	MNSGA-II	MOGA,[92] NSGA II,[93] QDGRP[94]

exposure problem which corresponds to the worst-case coverage in wireless sensor networks. Complexity analysis and simulation results show that the proposed algorithm achieved good performance with low complexity.

In Reference 97, a highly agile approach called backpressure routing for Delay Tolerant Networks (DTN), in which routing and forwarding decisions are made on a per-packet basis is considered by authors. It involved using information about queue backlogs, random walks, and data packet scheduling nodes that can make packet routing and forwarding decisions without the notion of end-to-end routes. Simulation results show that the proposed approach has advantages in terms of DTN networks. In Reference 98, a comparative analysis of routing protocols in wireless ad hoc sensor networks is vigorously done. This examines routing protocols for ad hoc sensor networks and evaluates them in terms of a given set of parameters. Also provides an overview of different protocols by presenting their characteristics and functionality, and then gives a comparison and discussion of their respective merits and drawbacks.

In Reference 99, authors proposed both a centralized heuristic to reduce its computational overhead and a distributed heuristic to make the algorithm scalable for large-scale network operations. Also, developed an Energy-efficient Delay Aware Lifetime-balancing protocol (EDAL) to be closely integrated with compressive sensing, an emerging technique that promises a considerable reduction in total traffic cost for collecting sensor readings under loose delay bounds. Based on both simulation and hardware testbed evaluation results, we can see that compared to baseline protocols, EDAL achieves a significant increase in network lifetime without violating the packet delay constraint. In Reference 100, the authors discuss applications of computational intelligence in sensor networks. Despite technological advances, sensor networks still face the challenges of communicating and processing large amounts of imprecise and partial data in resource-constrained environments. Further, the optimal deployment of sensors in an environment is also seen as an intractable problem. On the other hand, computational intelligence techniques like neural networks, evolutionary computation, swarm intelligence, and fuzzy systems are gaining popularity in solving intractable problems in various disciplines including sensor networks.

In Reference 101, the authors focus on the effect of performance metrics on the applications considered in defining the objective function of various intelligent routing protocols. The performance of reviewed protocols is analyzed based on routing metrics that are considered the main factors for defining the objective function to optimize the conflicting goals in WSNs. In Reference 102, the authors discuss the systematic survey on CI technique-based routing protocols in WSN. A comparative analysis of reviewed protocols with their strengths and limitations is also included in the survey. In Reference 103, the authors present a systematic review of the QoS mechanisms that have been employed by routing protocols and also highlight the performance issues of each mechanism. It also presents a comparative analysis of computational intelligence-based QoS-aware routing protocols with their strengths and limitations. In Reference 104, the authors employed weight values to determine the allocation of resources to individual sensor nodes, considering the volume of data packets received from neighboring sensor nodes. This approach led to enhanced performance, albeit at the cost of an elevated packet loss rate. In Reference 105, authors suggested various trade-offs associated with the use of a Cross-layer approach for the optimization of various features in networks. In Reference 106, a COARP clustering approach rooted in energy-conscious routing methods is introduced, and this method is subsequently extended to handle the

TABLE 10 Summary of Computational Intelligence (CI) techniques.

CI techniques	Advantages	Disadvantages
Ant colony optimization (ACO)	• Due to its distributed nature and capacity to endure in highly dynamic environments, ACO is the most chosen CI solution to manage multi-constrained routing. • ACO performs better in hierarchical WSN due to a large decrease in routing overheads and the number of packets routed to the intermediate node.	• ACO lacks the necessary information to find optimal paths at the beginning and takes more time to converge. • It generates high routing overheads in the form of forwarding and backward ants.
Artificial Bee Colony (ABC)	• The ABC algorithm achieves local optimization by exploitation, which is handled by observers and employed bees while achieving global optimization through exploration, which is carried out by artificial scouts. • It successfully resolves the multimodal and multivariable function optimization challenge.	Due to the random solutions produced by the components, ABC has a problem with sluggish convergence.
Fuzzy logic (FL)	• FL-based routing algorithms can resolve conflicting circumstances in WSNs without necessitating the use of a sophisticated mathematical model. • FL-based routing algorithms have the least amount of computing memory, design time, and system development cost.	• Fuzzy rules are not flexible to the network dynamics and must be relearned to meet changing network condition demands. • FL generates significant computing complexity and control overheads when making the routing decision.
Particle swarm optimization (PSO)	• PSO is another CI technique that is widely utilized in WSNs due to its simplicity in hardware or software implementation, quick convergence rate, and highly optimal solution. • The robustness and adaptability of PSO-based routing protocols toward the dynamic sink mobility and the network topology while keeping the lowest possible communication overheads have been improved.	PSO is not appropriate for real-time applications due to its iterative nature and huge memory constraints, which necessitate resource-rich base stations.
Genetic algorithm (GA)	GA-based routing protocols effectively address multi-objective routing problems without requiring prior knowledge of the network's topology, density, or size.	Its adoption in real-time applications is constrained by its slow convergence speed and its inability to adapt to shifting network topologies and communication link breakdowns.
Reinforcement learning (RL)	• RL-based routing protocols choose the best route through experiences and incentives; they do not require accurate knowledge of the network state for route reservation. • They are completely dispersed, simple to use, scalable, and adaptable to changing network topologies. • They can withstand node and link failures.	• The RL method requires enough time to investigate and understand the network dynamics, which reduces throughput and network delay during the first simulation phase. • The size of the network and node density, which rise exponentially with node density, determine the length of the learning phase in RL.

management of mobile sensor nodes. In Reference 107, authors focus essentially on future networks posing various challenges and exposed issues regarding congestion control and heterogeneous networks. In Reference 108, the authors introduced the Fuzzy-Logic Distance and energy-aware routing protocol (FLDEAR) designed specifically for delay-tolerant mobile sensor networks. FLDEAR aims to improve data packet delivery rates and alleviate data transmission overhead when compared to several existing routing protocols for Delay-Tolerant Mobile Sensor networks. In Reference 109, the authors discussed multimedia data transfer the various issues associated with it, and the optimization of QoS techniques in it. In Reference 110, the presented routing strategy combines the techniques of MM (Multi-Objective Optimization) and ABC (Artificial Bee Colony) methods to effectively choose the optimal Cluster Head (CH) nodes, ensuring equitable load distribution among them. This approach leads to enhanced energy efficiency and an extended network lifespan.

5 | RESEARCH GAPS AND OPEN ISSUES IN WSNS – A CRITIQUE

Based on the SLR formulated above in the context of WSNs, several unsolved challenges need to be investigated further. In the event-driven paradigm, data transfer is initiated when the event occurs. To develop a hybrid model, some networks include event-driven, continuous, and quiz-driven models. Service level (QoS) refers to the level of service required by the application. Before highlighting the open-ended stories, this section covers many concerns about style and design.

- Optimization Techniques and Machine Learning Algorithms: Emphasizes the importance of using optimization techniques and machine learning algorithms to improve Routing Protocol (RP) and clustering performance in Wireless Sensor Networks (WSNs).
- Energy Constraints and Battery Limitations: Highlights the limited availability of energy in WSNs due to battery-operated sensors with limited placement options. Emphasizes the need for energy-efficient solutions. Data Aggregation and Bandwidth Management: Discusses the necessity of aggregating redundant data packets to reduce communication strain and optimize network bandwidth.
- Scalability and Network Growth: Addresses the need for RPs that can scale as the network grows and the importance of balancing protocol strength with delay metrics.
- Dynamic Network Dynamics: Discusses the constantly changing topology of WSNs and the need for RPs to adapt to these changes for optimal network performance.
- Real-time Applications and Low Latency: Highlights the critical role of minimizing delay in time-bound and real-time applications to make the information useful.
- Hardware Limitations: Points out the limitations of hardware resources in WSNs and the necessity of developing better network protocols and software techniques to work within these constraints.
- Fault Tolerance: Discusses the importance of fault tolerance to ensure that network functions continue even when individual sensors fail.
- Data Distribution Models: Addresses various data delivery strategies and their impact on RP, including continuous, query-driven, event-based, and hybrid models.
- Quality of Service (QoS): Emphasizes the influence of QoS requirements, such as error rate, data consistency, and transport delays, on the choice of RP.
- Power Consumption: Discusses the significance of power consumption in WSNs and the need for integration algorithms to extend network life.
- Open Research Questions: Lists several open research questions, including hierarchical network RP, cross-layer routing, multiple and mobile sinks, unique MAC protocols, multichannel RP, distributed control, QoS-aware protocols, SN mobility, application-specific RPs, mathematical modeling, real testbeds/hardware, and dynamic localization techniques.
- Recommendation for Routing Protocol and Metrics: Suggests using RPL as the routing protocol and integrating metrics like Remaining Node Energy (RNE) with Expected Transmission Number (ETX) to optimize routing decisions.
- Hierarchical Routing Protocols: Highlights the use of hierarchical routing protocols, particularly the LEACH Protocol, to reduce energy consumption and improve efficiency in WSNs.
- Research Areas and Future Directions: Encourages further research in energy efficiency, network longevity, and path localization in dynamic WSNs, with a focus on optimization and machine learning techniques.
- Energy Harvesting: Discusses the potential of energy harvesting to extend WSN lifetime and suggests considering how to best utilize various energy sources in future optimization techniques.
- Customized Solutions: Acknowledges that while many algorithms have broad applicability, customizing the network for specific applications can pose unique challenges that require further research.

The provided critique outlines a comprehensive set of contributions, challenges, and research directions related to Wireless Sensor Networks (WSNs) and Routing Protocols (RPs).

6 | CONCLUSION AND FUTURE WORK

We examine the protocol techniques for the specified protocols, as well as their benefits and drawbacks. The primary goal of this research is to present a complete analysis and current achievements in the study of WSNs in terms of energy efficiency, network longevity, and path localization to dynamic changes within WSNs. Through empirical research, we concluded that the optimum threshold could be achieved when the receiver's power levels equally distribute the power dissipation throughout the network. While addressing major challenges in WSNs, this systematic analysis showed numerous efficient solutions in the literature. Optimization and machine learning approaches were given priority because they are two of the most recent advancements in WSNs. Most changes adapt programs to exploit architecture. Sometimes performance gain is limited by power consumption. Saving energy might open doors for other optimizations. This state of art study may help all the enthusiasts who are working on energy optimization techniques in WSNs.

With the quick advancement of computer technology, intelligent algorithms have been successfully created to address real-world issues of great computational complexity and have found successful applications in numerous fields. However, the majority of intelligent algorithms are exclusively utilized in terrestrial wireless sensor networks because of the constraints of the environment. The impact of computational intelligence and machine learning research on the creation of energy-efficient routing protocols is summarized and open research areas to assist future researchers in WSN research. Although the strategies in this study aim to balance energy consumption across all the sensors, WSN lifetime is still limited by the limited capacity of sensor batteries. Some WSNs permit energy harvesting, whereby sensors collect energy via a variety of processes (such as solar power, radio frequency energy transfer, and microwave energy transfer) to replenish their batteries. The best way to use these energy sources to increase network lifetime must be considered in future optimization techniques. The discussion of numerous optimization issues, such as when and how to harvest energy to run a WSN, is also made possible by the use of such methodologies. The majority of the algorithms provided in this survey are aimed toward models with broad applicability. The network will need to be customized for the application in question when these methods are implemented, revealing substantially richer classes of challenges for research. In the future, it will eventually be used to implement additional QoS as research.

FUNDING INFORMATION

No funding is provided for the preparation of manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

REFERENCES

1. Yenke BO, Sambo DW, Ado AA, Gueroui A. MMEDD: multithreading model for an efficient data delivery in wireless sensor networks. *Int J Commun Netw Inf Secur*. 2016;8:179-186.
2. Boukerche A, Ahmad MZ, Turgut D, Turgut B. A taxonomy of routing protocols in sensor networks. *Algorithms and Protocols for Wireless Sensor Networks.* John Wiley & Sons, Inc; 2008:129–160.
3. Alippi C, Anastasi G, di Francesco M, Roveri M. Energy management in wireless sensor networks with energy-hungry sensors. *IEEE Instrum Meas Mag*. 2009;12(2):16-23.
4. Sabor N, Sasaki S, Abo-Zahhad M, Ahmed SM. A comprehensive survey on hierarchical-based routing protocols for mobile wireless sensor networks: review, taxonomy, and future directions. *Wirel Commun Mob Comput*. 2017;2017:1-23.
5. Avril F, Bernard T, Bui A, Sohier D. Clustering and communications scheduling in WSNs using mixed integer linear programming. *J Commun Netw*. 2014;16(4):421-429.
6. Ding G et al. Decentralized sensor selection for cooperative spectrum sensing based on unsupervised learning. 2012 IEEE International Conference on Communications (ICC). 2012.
7. Coutinho RW, Boukerche A, Vieira LF, Loureiro AA. EnOR: Energy balancing routing protocol for underwater sensor networks. 2017 IEEE International Conference on Communications (ICC). 2017.
8. Emokpae LE, Liu Z, Edelmann GF, Younis M. A cross-stack QoS routing approach for underwater acoustic sensor networks. 2018 Forth Underwater Communications and Networking Conference (UComms). IEEE. 2018.
9. Wang H, Wang S, Zhang E, Lu L. An energy balanced and lifetime extended routing protocol for underwater sensor networks. *Sensors*. 2018;18(5):1596.

10. Javaid N, Karim OA, Sher A, et al. Q-Learning for energy balancing and avoiding the void hole routing protocol in underwater sensor networks. 2018 14th International Wireless Communications & Mobile Computing Conference (IWCMC). IEEE. 2018.
11. Liu J, Yu M, Wang X, Liu Y, Wei X. RECRP: A reliable energy-efficient cross-layer routing protocol in UWSNs. 2018 OCEANS-MTS/IEEE Kobe Techno-Oceans (OTO). IEEE. 2018.
12. Rahman Z, Hashim F, Rasid MFA, Othman M. Totally opportunistic routing algorithm (TORA) for underwater wireless sensor network. *PLoS One*. 2018;13(6):e0197087.
13. Basagni S, Di Valerio V, Gjanci P, Petrioli C. Harnessing hydro: harvesting-aware data routing for underwater wireless sensor networks. Proceedings of the Eighteenth ACM International Symposium on Mobile Ad Hoc Networking and Computing. 2018.
14. Shah S, Khan A, Ali I, Ko KM, Mahmood H. Localization free energy efficient and cooperative routing protocols for underwater wireless sensor networks. *Symmetry*. 2018;10(10):498.
15. Li X, Hu X, Li W, Hu H. A multi-agent reinforcement learning routing protocol for underwater optical sensor networks. ICC 2019–2019 IEEE International Conference on Communications (ICC). 2019.
16. Khan ZA, Latif G, Sher A, et al. Efficient routing for corona based underwater wireless sensor networks. *Comput Secur*. 2019;101(7):831-856.
17. Saeed K, Khalil W, Ahmed S, Ahmad I, Khattak MNK. SEECR: secure energy efficient and cooperative routing protocol for underwater wireless sensor networks. *IEEE Access*. 2020;8:107419-107433.
18. Accessed on January 8th 2022. https://libguides.murdoch.edu.au/systematic/PICO
19. Kulkarni RV, Förster A, Venayagamoorthy GK. Computational intelligence in wireless sensor networks: a survey. *IEEE Commun Surv Tutorials*. 2010;13(1):68-96.
20. Akkaya K, Younis M. A survey on routing protocols for wireless sensor networks. *Ad Hoc Netw*. 2005;3(3):325-349.
21. Kumar J, Tripathi S, Tiwari RK. A survey on routing protocols for wireless sensor networks using swarm intelligence. *Int J Internet Technol Secured Trans*. 2016;6(2):79-102.
22. Ari AAA et al. Concepts and evolution of research in the field of wireless sensor networks. 2015. arXiv Preprint arXiv:1502.03561.
23. Jin Z, Jian-Ping Y, Si-Wang Z, Ya-Ping L, Guang L. A survey on position-based routing algorithms in wireless sensor networks. *Algorithms*. 2009;2(1):158-182.
24. Intanagonwiwat C, Govindan R, Estrin D. Directed diffusion: A scalable and robust communication paradigm for sensor networks. Proceedings of the 6th annual international conference on Mobile computing and networking. 2000.
25. Kumar AGG, Thiyagarajan R, Sripriya N. Data centric based routing protocols for wireless sensor networks: a survey. *Int J Sci Res Publ*. 2014;4:1-5.
26. Bhanderi M, Shah H. Machine learning for wireless sensor network: a review, challenges and applications. *Adv Electron Electr Eng*. 2014;4:475-486.
27. Liu D, Ning P, Du W. Group-based key predistribution for wireless sensor networks. *ACM Trans Sensor Networks*. 2008;4(2):1-30.
28. Lloret J, Garcia M, Boronat F, Tomas J. A group-based protocol for large wireless AD-HOC and sensor networks. NOMS Workshops 2008-IEEE Network Operations and Management Symposium Workshops. 2008.
29. Wu G, Li H, Yao L. A group-based mobile agent routing protocol for multitype wireless sensor networks. 2010 IEEE/ACM Int'l Conference on Green Computing and Communications & Int'l Conference on Cyber, Physical and Social Computing. IEEE. 2010.
30. Heinzelman WR, Chandrakasan A, Balakrishnan H. Energy-efficient communication protocol for wireless microsensor networks. Proceedings of the 33rd annual Hawaii international conference on system sciences. IEEE. 2000.
31. Manjeshwar A, Agrawal DP. TEEN: ARouting protocol for enhanced efficiency in wireless sensor networks. *Ipdps*. 2001;2001(1):189.
32. Manjeshwar A, Agrawal DP. APTEEN: a hybrid protocol for efficient routing and comprehensive information retrieval in wireless sensor networks. Parallel and Distributed Processing Symposium, International IEEE Computer Society. 2002 3.
33. Shabbir N, Nawaz R, Iqbal MN, Zafar J. Routing protocols for small scale WLAN based Wireless Sensor Networks (WSNs). 2015 9th International Conference on Sensing Technology (ICST). IEEE. 2015.
34. Solaiman B, Sheta A. Computational intelligence for wireless sensor networks: applications and clustering algorithms. *Int J Comput Appl*. 2013;73(15):1-8.
35. Bayraklı S, Erdogan SZ. Genetic algorithm based energy efficient clusters (GABEEC) in wireless sensor networks. *Procedia Comput Sci*. 2012;10:247-254.
36. Liu J-L, Ravishankar CV. LEACH-GA: genetic algorithm-based energy-efficient adaptive clustering protocol for wireless sensor networks. *Int J Mach Learn Comput*. 2011;1(1):79.
37. Hussain S, Matin AW, Islam O. Genetic algorithm for hierarchical wireless sensor networks. *J Networks*. 2007;2(5):87-97.
38. Wazed S, Bari A, Jaekel A, Bandyopadhyay S. Genetic algorithm based approach for extending the lifetime of two-tiered sensor networks. 2007 2nd International Symposium on Wireless Pervasive Computing. IEEE. 2007.
39. Dorigo M, Blum C. Ant colony optimization theory: a survey. *Theor Comput Sci*. 2005;344(2–3):243-278.
40. Wang L, Zhang R, Geng S. An energy-balanced ant-based routing protocol for wireless sensor networks. 2009 5th International Conference on Wireless Communications, Networking and Mobile Computing. IEEE. 2009.
41. Ziyadi M, Yasami K, Abolhassani B. Adaptive clustering for energy efficient wireless sensor networks based on ant colony optimization. 2009 Seventh Annual Communication Networks and Services Research Conference. IEEE. 2009.
42. Yang J, Xu M, Zhao W, Xu B. A multipath routing protocol based on clustering and ant colony optimization for wireless sensor networks. *Sensors*. 2010;10(5):4521-4540.

43. Ganesan D, Govindan R, Shenker S, Estrin D. Highly-resilient, energy-efficient multipath routing in wireless sensor networks. *ACM SIGMOBILE Mobile Comput Commun Rev*. 2001;5(4):11-25.
44. Tu Z, Wang Q, Shen Y. Optimal mobile agent routing for data fusion in distributed sensor networks using improved ant colony algorithm. 2008 IEEE Instrumentation and Measurement Technology Conference. 2008.
45. Wang J, Cao Y, Li B, Kim HJ, Lee S. Particle swarm optimization based clustering algorithm with mobile sink for WSNs. *Futur Gener Comput Syst*. 2017;76:452-457.
46. Helmy AO, Ahmed S, Hassenian AE. Artificial fish swarm algorithm for energy-efficient routing technique. *Intelligent Systems 2014*. Springer, Cham; 2015:509-519.
47. Liu M, Xu S, Sun S. An agent-assisted QoS-based routing algorithm for wireless sensor networks. *J Netw Comput Appl*. 2012;35(1):29-36.
48. Kuila P, Jana PK. Energy efficient clustering and routing algorithms for wireless sensor networks: particle swarm optimization approach. *Eng Appl Artif Intell*. 2014;33:127-140.
49. Brar GS, Rani S, Chopra V, Malhotra R, Song H, Ahmed SH. Energy efficient direction-based PDORP routing protocol for WSN. *IEEE Access*. 2016;4:3182-3194.
50. Chen H, Li X, Zhao F. A reinforcement learning-based sleep scheduling algorithm for desired area coverage in solar-powered wireless sensor networks. *IEEE Sensors J*. 2016;16(8):2763-2774.
51. Yang B, Lei Y, Yan B. Distributed multi-human location algorithm using naive Bayes classifier for a binary pyroelectric infrared sensor tracking system. *IEEE Sensors J*. 2015;16(1):216-223.
52. Shu J, Liu S, Liu L, Zhan L, Hu G. Research on link quality estimation mechanism for wireless sensor networks based on support vector machine. *Chin J Electron*. 2017;26(2):377-384.
53. Gil P, Martins H, Januário F. Outliers detection methods in wireless sensor networks. *Artif Intell Rev*. 2019;52(4):2411-2436.
54. Shamshirband S, Patel A, Anuar NB, Kiah MLM, Abraham A. Cooperative game theoretic approach using fuzzy Q-learning for detecting and preventing intrusions in wireless sensor networks. *Eng Appl Artif Intell*. 2014;32:228-241.
55. Haque SA, Rahman M, Aziz SM. Sensor anomaly detection in wireless sensor networks for healthcare. *Sensors*. 2015;15(4):8764-8786.
56. Awan SW, Saleem S. Hierarchical clustering algorithms for heterogeneous energy harvesting wireless sensor networks. 2016 International Symposium on Wireless Communication Systems (ISWCS). IEEE. 2016.
57. Chen F, Fu Z, Yang Z. Wind power generation fault diagnosis based on deep learning model in internet of things (IoT) with clusters. *Clust Comput*. 2019;22(6):14013-14025.
58. Lee EK, Viswanathan H, Pompili D. RescueNet: reinforcement-learning-based communication framework for emergency networking. *Comput Netw*. 2016;98:14-28.
59. Rizk R, Magdy SM, Zaki FW. Energy efficiency of virtual multi-input, multi-output based on sensor selection in wireless sensor networks. *Wirel Commun Mob Comput*. 2015;15(1):1-15.
60. Jiang H, Sun Y, Sun R, Xu H. Fuzzy-logic-based energy optimized routing for wireless sensor networks. *Int J Distrib Sens Networks*. 2013;9(8):216561.
61. Tamandani YK, Bokhari MU. SEPFL routing protocol based on fuzzy logic control to extend the lifetime and throughput of the wireless sensor network. *Wirel Netw*. 2016;22(2):647-653.
62. Nayak P, Devulapalli A. A fuzzy logic-based clustering algorithm for WSN to extend the network lifetime. *IEEE Sensors J*. 2015;16(1):137-144.
63. Sert SA, Bagci H, Yazici A. MOFCA: multi-objective fuzzy clustering algorithm for wireless sensor networks. *Appl Soft Comput*. 2015;30:151-165.
64. Minhas MR, Gopalakrishnan S, Leung VCM. Multiobjective routing for simultaneously optimizing system lifetime and source-to-sink delay in wireless sensor networks. 2009 29th IEEE International Conference on Distributed Computing Systems Workshops. IEEE. 2009.
65. Al-Quh AHM, Ismail IAS, Kotb AM. FEQRP: a fuzzy based energy-efficient and QoS routing protocol over WSNs. IOSR journal of. *Comput Eng*. 2016;1(18):79-89.
66. Forster A, Murphy AL. FROMS: Feedback routing for optimizing multiple sinks in WSN with reinforcement learning. 2007 3rd international conference on intelligent sensors, sensor networks and information. IEEE. 2007.
67. Hu T, Fei Y. QELAR: a machine-learning-based adaptive routing protocol for energy-efficient and lifetime-extended underwater sensor networks. *IEEE Trans Mob Comput*. 2010;9(6):796-809.
68. Kiani F, Amiri E, Zamani M, Khodadadi T, Abdul Manaf A. Efficient intelligent energy routing protocol in wireless sensor networks. *Int J Distrib Sens Networks*. 2015;11(3):618072.
69. Liang X, Balasingham I, Byun S-S. A multi-agent reinforcement learning based routing protocol for wireless sensor networks. 2008 IEEE International Symposium on Wireless Communication Systems. IEEE. 2008.
70. Liang X, Balasingham I, Byun S-S. A reinforcement learning based routing protocol with QoS support for biomedical sensor networks. 2008 First International Symposium on Applied Sciences on Biomedical and Communication Technologies. IEEE. 2008.
71. Jafarzadeh SZ, Moghaddam MHY. Design of energy-aware QoS routing algorithm in wireless sensor networks using reinforcement learning. 2014 4th International Conference on Computer and Knowledge Engineering (ICCKE). IEEE. 2014.
72. Camilo T, Carreto C, Silva JS, Boavida F. An energy-efficient ant-based routing algorithm for wireless sensor networks. *International Workshop on Ant Colony Optimization and Swarm Intelligence*. Springer; 2006.
73. Mohajerani A, Gharavian D. An ant colony optimization based routing algorithm for extending network lifetime in wireless sensor networks. *Wirel Netw*. 2016;22(8):2637-2647.

74. Zhao Z, Hou M, Zhang N, Gao M. Multipath routing algorithm based on ant colony optimization and energy awareness. *Wirel Pers Commun*. 2017;94(4):2937-2948.
75. Yu X, Luo J, Huang J. An ant colony optimization-based QoS routing algorithm for wireless multimedia sensor networks. 2011 IEEE 3rd International Conference on Communication Software and Networks. IEEE. 2011.
76. Malik SK, Dave M, Dhurandher SK, Woungang I, Barolli L. An ant-based QoS-aware routing protocol for heterogeneous wireless sensor networks. *Soft Comput*. 2017;21(21):6225-6236.
77. Cobo L, Quintero A, Pierre S. Ant-based routing for wireless multimedia sensor networks using multiple QoS metrics. *Comput Netw*. 2010;54(17):2991-3010.
78. Zungeru AM, Seng KP, Ang LM, Chong Chia W. Energy efficiency performance improvements for ant-based routing algorithm in wireless sensor networks. *J Sensors*. 2013;2013:1-17.
79. Tong M, Chen Y, Chen F, Wu X, Shou G. An energy-efficient multipath routing algorithm based on ant colony optimization for wireless sensor networks. *Int J Distrib Sens Networks*. 2015;11(6):642189.
80. Wang J, Cao J, Sherratt RS, Park JH. An improved ant colony optimization-based approach with mobile sink for wireless sensor networks. *J Supercomput*. 2018;74(12):6633-6645.
81. Azharuddin M, Jana PK. Particle swarm optimization for maximizing lifetime of wireless sensor networks. *Comput Electr Eng*. 2016;51:26-42.
82. Elhabyan RSY, Yagoub MCE. Two-tier particle swarm optimization protocol for clustering and routing in wireless sensor network. *J Netw Comput Appl*. 2015;52:116-128.
83. Rao PC, Jana PK, Banka H. A particle swarm optimization based energy efficient cluster head selection algorithm for wireless sensor networks. *Wirel Netw*. 2017;23(7):2005-2020.
84. Kumar R, Kumar D. Multi-objective fractional artificial bee colony algorithm to energy aware routing protocol in wireless sensor network. *Wirel Netw*. 2016;22(5):1461-1474.
85. Wang H, Chen Y, Dong S. Research on efficient-efficient routing protocol for WSNs based on improved artificial bee colony algorithm. *IET Wireless Sens Syst*. 2017;7(1):15-20.
86. Saleem M, Ullah I, Farooq M. BeeSensor: an energy-efficient and scalable routing protocol for wireless sensor networks. *Inf Sci*. 2012;200:38-56.
87. Cai X, Duan Y, He Y, Yang J, Li C. Bee-sensor-C: an energy-efficient and scalable multipath routing protocol for wireless sensor networks. *Int J Distrib Sens Networks*. 2015;11(3):976127.
88. Ari AAA, Yenke BO, Labraoui N, Damakoa I, Gueroui A. A power efficient cluster-based routing algorithm for wireless sensor networks: honeybees swarm intelligence based approach. *J Netw Comput Appl*. 2016;69:77-97.
89. Gupta SK, Kuila P, Jana PK. GAR: an energy efficient GA-based routing for wireless sensor networks. *International Conference on Distributed Computing and Internet Technology*. Springer; 2013.
90. Singh SP, Sharma SC. Genetic-algorithm-based energy-efficient clustering (GAEEC) for homogenous wireless sensor networks. *IETE J Res*. 2018;64(5):648-659.
91. Bhatia T, Kansal S, Goel S, Verma AK. A genetic algorithm based distance-aware routing protocol for wireless sensor networks. *Comput Electr Eng*. 2016;56:441-455.
92. Murugeswari R, Radhakrishnan S, Devaraj D. A multi-objective evolutionary algorithm based QoS routing in wireless mesh networks. *Appl Soft Comput*. 2016;40:517-525.
93. Saxena N, Roy A, Shin J. A multi-objective genetic algorithmic approach for QoS-based energy-efficient sensor routing protocol. *Asia-Pacific Network Operations and Management Symposium*. Springer; 2007.
94. EkbataniFard GH, Monsefi R, Akbarzadeh TMR, Yaghmaee MH. A multi-objective genetic algorithm based approach for energy efficient QoS-routing in two-tiered wireless sensor networks. IEEE 5th International Symposium on Wireless Pervasive Computing 2010. IEEE. 2010.
95. Busch C, Kannan R, Vasilakos AV. Approximating congestion+ dilation in networks via "quality of routing" games. *IEEE Trans Comput*. 2011;61(9):1270-1283.
96. Liu L, Song Y, Zhang H, Ma H, Vasilakos AV. Physarum optimization: a biology-inspired algorithm for the steiner tree problem in networks. *IEEE Trans Comput*. 2013;64(3):818-831.
97. Dvir A, Vasilakos AV. Backpressure-based routing protocol for DTNs. Proceedings of the ACM SIGCOMM 2010 Conference. 2010.
98. Vasilakos A, Pedrycz W. *Ambient Intelligence, Wireless Networking, and Ubiquitous Computing*. Artech House, Inc.; 2006.
99. Yao Y, Cao Q, Vasilakos AV. EDAL: an energy-efficient, delay-aware, and lifetime-balancing data collection protocol for heterogeneous wireless sensor networks. *IEEE/ACM Trans Networking*. 2014;23(3):810-823.
100. Mishra BB, Dehiru S, Panigrahi BK, et al. *Computational Intelligence in Sensor Networks*. Springer; 2019.
101. Saxena R, Husain A. Application of computational intelligence techniques for optimization of routing protocols in wireless sensor networks: a survey. *INFOCOMP J Comput Sci*. 2020;19(1):1-8.
102. Kaur T, Kumar D. Computational intelligence-based energy efficient routing protocols with QoS assurance for wireless sensor networks: a survey. *Int J Wirel Mob Comput*. 2019;16(2):172-193.
103. Kaur T, Kumar D. A survey on QoS mechanisms in WSN for computational intelligence based routing protocols. *Wirel Netw*. 2020;26(4):2465-2486.
104. Tabibi S, Ghaffari A. Energy-efficient routing mechanism for mobile sink in wireless sensor networks using particle swarm optimization algorithm. *Wirel Pers Commun*. 2019;104:199-216.

105. Vivekananda GN, Reddy PC. Critical analysis of cross-layer approach. 2015 International Conference on Green Computing and Internet of Things (ICGCIoT). IEEE. 2015.
106. Khabiri M, Ghaffari A. Energy-aware clustering-based routing in wireless sensor networks using cuckoo optimization algorithm. *Wirel Pers Commun*. 2018;98:2473-2495.
107. Vivekananda GN, Reddy PC. Critical analysis of congestion control for the future networks. *Emerging Trends in Electrical, Communications and Information Technologies*. Springer; 2017:175-181.
108. Mottaghinia Z, Ghaffari A. Fuzzy logic based distance and energy-aware routing protocol in delay-tolerant mobile sensor networks. *Wirel Pers Commun*. 2018;100:957-976.
109. Vivekananda GN, Ilknur A. A congestion avoidance mechanism in multimedia transmission over MANET using SCTP multi-streaming. *Multimed Tools Appl*. 2020;79(23):16823-16844.
110. Sefati SS, Abdi M, Ghaffari A. QoS-based routing protocol and load balancing in wireless sensor networks using the markov model and the artificial bee colony algorithm. *Peer-to-Peer Networking Appl*. 2023;16(3):1499-1512.

How to cite this article: Lakshmi MS, Ramana KS, Ramu G, Shyam Sunder Reddy K, Sasikala C, Ramesh G. Computational intelligence techniques for energy efficient routing protocols in wireless sensor networks: A critique. *Trans Emerging Tel Tech*. 2023;e4888. doi: 10.1002/ett.4888