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# Comprehensive review for energy efficient hierarchical routing protocols on wireless sensor networks

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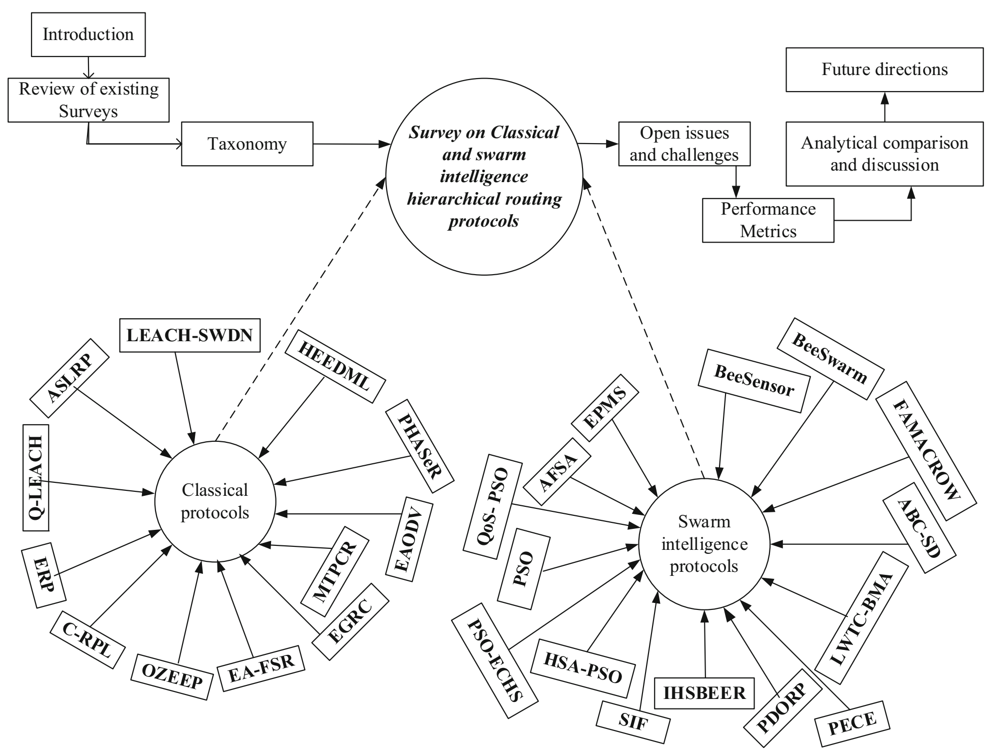
## Abstract

In recent years, wireless sensor networks (WSNs) have played a major role in applications such as tracking and monitoring in remote environments. Designing energy efficient protocols for routing of data events is a major challenge due to the dynamic topology and distributed nature of WSNs. Main aim of the paper is to discuss hierarchical routing protocols in order to improve the energy efficiency and network lifetime. This paper provides a discussion about hierarchical energy efficient routing protocols based on classical and swarm intelligence approach. The routing protocols belonging to both categories can be summarized according to energy efficiency, data aggregation, location awareness, QoS, scalability, load balancing, fault tolerance, query based and multipath. A systematic literature review has been conducted for hierarchical energy efficient routing protocols reported from 2012 to 2017. This survey provides a technical direction for researchers on how to develop routing protocols. Finally, research gaps in the reviewed protocols and the potential future aspects have been discussed.

## Graphical Abstract

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**Keywords** Wireless sensor network · Routing protocols · Hierarchical · Classical · Swarm intelligence · QoS

## 1 Introduction

WSNs are comprised of a large number of nodes which allow accumulated data transfer through the network to sink or base stations (BSs) [1]. These networks find numerous attractive applications in fields such as business, healthcare, military surveillance, air pollution control, river level variation monitoring, intelligent highway designing and remote health assistance etc. While establishing such applications, the sensor nodes utilize huge amount of energy for communication, data processing and sensing [2]. Nowadays industry wide, research is going on with a special focus on energy consumption, network topology maintenance and finding a better route for data transmission to maximize the network life time.

Wang et al. [3, 4] have made a significant contribution for improving energy efficiency in WSNs through green computing. The authors have proposed an energy efficient Industrial Internet of Things (IIoT) architecture [3]. The proposed hierarchical framework is a three layered architecture comprising of sense layer, gateway layer and control layer which contributes to load balancing and enhances the network lifetime as well. Authors have also proposed a MAC layer activity scheduling mechanism which leads to energy conservation by switching nodes to sleep state depending upon sleep/wake up time interval. Simulation proves that proposed IIoT architecture provides a significant improvement in resource utilization and energy consumption. Proposed IIoT architecture provides an energy efficient solution to energy consumption issues encountered in the control and surveillance of industry plant through IoT.

Further, Wang et al. [4] have proposed an efficient, fault tolerant and reliable interest based reduced variable neighborhood search (RVNS) queue based architecture (IRQA) to alleviate the issues related to data collection, processing and analysis for mobile eHealth networks. The concept of Big data is utilized for rapid processing of large volumes of data in mobile eHealth networks. Interest based matching assures the reliability of data transmission by establishing a fault tolerant mechanism. Specially designed RVNS queue enhances the processing speed through RVNS algorithm by applying combinatorial optimization. The proposed IRQA framework provides an energy efficient solution for healthcare service providers which rapidly processes and analyzes large volumes of valuable data related to health services. Simulation results prove that RVNS queue exhibits a stable behavior and is able to provide quick response for large volumes of data processing. Special design of RVNS queue analyzes and reports important data in advance by managing a prioritized sequence of data processing events.

Figure 1 illustrates the architecture of WSNs.

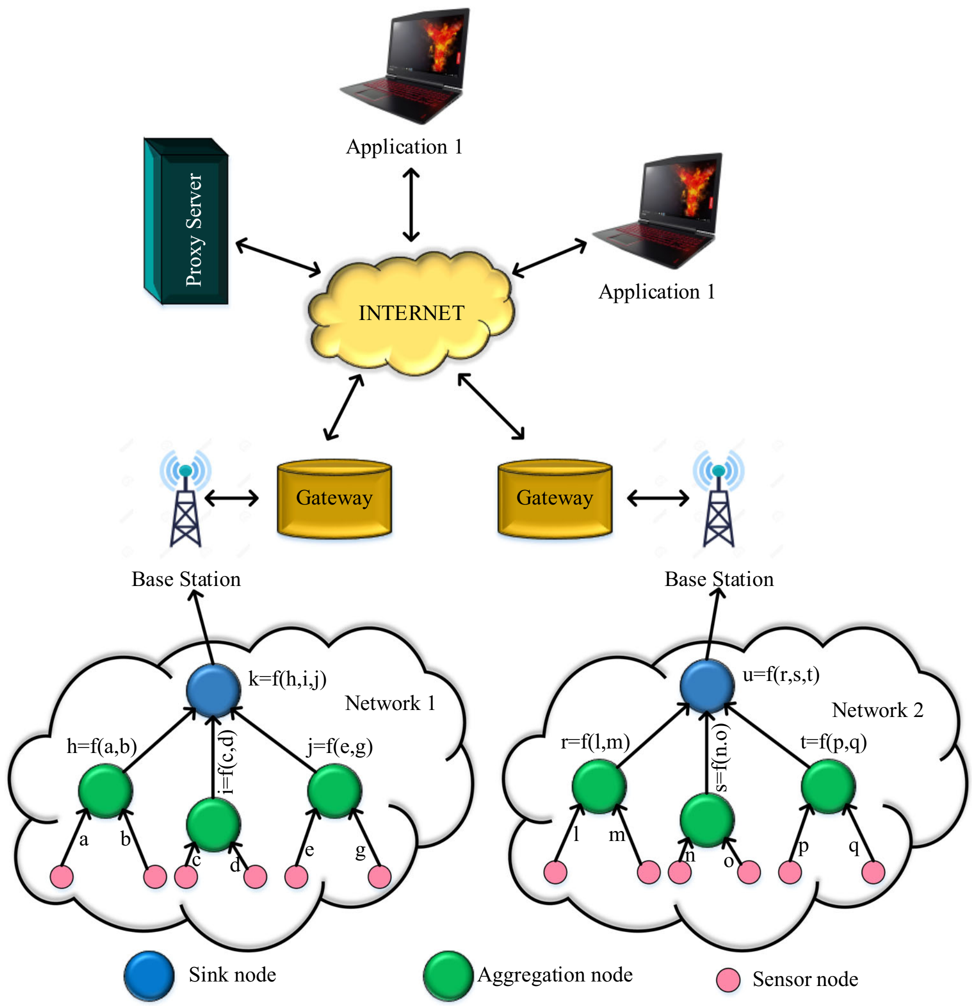
Energy efficiency is a major cause of concern during the network design phase because sensors are manufactured with non-rechargeable batteries. Route selection is a critical activity while transmitting messages from source to destination. Major amount of energy is consumed during the data transmission. Hierarchical routing architecture has proved to be extremely effective in solving the problem of excessive energy consumption. In clustering, the network is divided into multiple clusters. During data transmission process, the intermediate sensor nodes assist the source node to send data packets to the destination through routing paths [5, 6]. Concept of data aggregation results in efficient use of limited resources of WSNs. Nowadays, cluster based routing protocol are attaining greater importance. In cluster based routing different sensor nodes form a cluster (a group of nodes) which contains one main node called as Cluster Head (CH) [7]. Classical and swarm intelligence approaches utilize their resources which result in efficient solution for energy consumption. Conventional protocols are called as classical protocols. Self-organized or biologically inspired protocols are called as swarm intelligence-based protocols. Swarm intelligence based clustering protocols have a major objective of minimizing the energy consumption by performing dynamic clustering on sensor nodes during the setup phase.

Low-Energy Adaptive Clustering Hierarchy (LEACH) was the first protocol used for decreasing the network energy consumption by arranging nodes into clusters [8]. Every round of LEACH operations is divided into setup phase and steady state phase. Active and passive clustering are performed in separate rounds which results in energy efficient behavior [9, 10]. It has been proved through simulative and analytical technique that a MAC protocol can be used for reducing the network power consumption based on the duty cycle of the node [11]. Ant colony optimization based fuzzy system is one of the basic protocol in swarm intelligence based approach, used for enhancing the network lifetime [12, 13].

The major contribution of this review is as follows.

1. This paper offers an insight into energy efficient hierarchical routing protocols; particularly classical and swarm intelligence (SI) based routing protocols.

**Fig. 1** Architecture of WSNs




2. A taxonomy of routing protocols classification is presented with basic description and working principle.
3. A detailed analysis of protocols with their objectives, classifications, methods, performance metrics, advantages and future scope is presented. The performance of these protocols is compared based on various metrics.
4. This review summarizes a comprehensive survey on hierarchical routing protocols in terms of classification, energy efficiency, data aggregation, location awareness, QoS, scalability, load balancing, fault tolerance, multipath and query based.
5. This paper highlights some of the open issues related to this research domain. Finally, new research directions have been proposed for further development in this domain.

Subsequent sections have been ordered as follows: Section 2 analyzes the former survey papers based on hierarchical routing protocols. Section 3 presents a taxonomy on classification of routing protocols. Section 4 deals with the description about classical hierarchical routing protocols. Section 5 provides the description about SI based hierarchical routing protocols. Section 6 explains the challenges and open issues of routing protocols. Section 7 discusses the performance metrics for routing protocols. Section 8 summarizes the comparison of various protocols. Section 9 concludes the paper along with future directions for research.

## 2 Related work

*Some of the surveys based on routing protocols in WSNs are documented below.*

### 2.1 Previous surveys on classical routing protocols

In [14], topology management and factors influencing the performance of chain-based and cluster-based hierarchical network protocols were discussed. Authors also investigated that how various issues related to sensor connectivity like sleep/idle pairing, power control in topology setup, data transmission control affect the performance of protocols. A comparison of some chain based routing protocols was presented as part of their study.

In [15], a survey on energy efficient routing protocols was presented. Various protocols were categorized as per communication model, reliability, network structure and topology. In order to address energy consumption issue effectively, Al-Karaki classification was further expanded. The requirements and features of each category were presented along with design issues. Energy consumption models, route selection policies, traffic patterns were also discussed.

Physical layer optimizations and routing solutions for network layer were suggested to provide an energy efficient solution for fixing the energy consumption issue in application specific WSN [16]. For designing such a network, the trade-off between network lifetime extension and application requirements was presented in a top-down manner. First, the application requirements were finalized and then accordingly data routing techniques were selected as per energy consumption. Further, these techniques were analyzed to provide an efficient routing solution.

In article [17], a review of hierarchical routing, its classification and logical topologies were discussed. Tree-based, area-based, chain-based and grid-based routing approaches were described. Hierarchical routing protocols belonging to these categories were discussed and compared on the basis of their benefits and drawbacks. Authors also focused on the issues associated with design of hierarchical networks.

Based on user-defined parameters, heterogeneous routing protocols were classified in [18]. Authors presented taxonomy of heterogeneous routing schemes based on node heterogeneity parameters which are energy heterogeneity, computational heterogeneity, link heterogeneity and hybrid category. Heterogeneous protocol comparisons were presented depending upon two and three levels of node heterogeneity for energy consumption which considers CH selection method, single hop/multi hop topology, energy efficiency, application specific nature, security. Issues related to sending sensitive information to the destination were discussed considering factors such as latency, stability, energy, reliability, and security.

In article [19], authors investigated hierarchical routing protocols to overcome the depletion of energy and hence improve the lifetime of network. Certain improvements on hierarchical routing protocols were also presented as part of their study.

In [20], a conceptual illustration of various opportunistic routing protocols was presented with their performance metrics and advantages. The approaches discussed were mainly focused on reducing data redundancy, improving energy saving and enhancing network utilization. Energy efficient methods were introduced for enhancing throughput, efficiency, and reliability. Opportunistic protocol comparison was presented by considering forward list selection parameter, priority metric for node selection, synchronization parameter, delay, duplicate packet measure, energy efficiency and protocol application domain.

Multipath routing schemes were discussed briefly in [21] for reducing the transmission delay and congestion to enhance the utilization rate of channel, for Wireless Multimedia Sensor Networks (WMSN). The working principle, advantages, disadvantages of multipath routing schemes were listed as part of their study.

### 2.2 Previous surveys on swarm intelligence based routing protocols

In [22] authors investigated decentralized energy aware routing methods and procedures to lower down energy consumption. Active and passive energy aware methods were presented. The concept of active energy awareness schemes based on Media Access Control (MAC), network layer and transport layer was provided. Work flow model for Bee Colony Optimization (BCO), Particle Swarm Optimization (PSO) was depicted. Various application areas of Ant Colony Optimization (ACO) in the field of engineering were characterized. SI based energy aware protocols were discussed and comparison of various ACO based protocols was presented.

In article [23], basics of SI based meta-heuristic were presented. Authors highlighted the concept of ACO, (PSO), Bacterial foraging optimization (BFO), artificial bee colony (ABC). Termite colony optimization and spider monkey optimization technique based on fission–fusion concept were discussed. Spider monkey optimization avoids the selection of low residual energy nodes during optimal path selection, so as to avoid path failures or network breakdown. Comparison of some SI based protocols based on their attributes was presented.

Multi-Objective Optimization (MOO) techniques along with swarm intelligence algorithms were presented to introduce the development efforts for surveillance and monitoring [24]. The trade-off among network's packet loss rate, lifetime, energy dissipation and coverage was a typical problem in WSN. The requirements of several optimization approaches like heuristics/meta-heuristics based optimization and mathematical programming were discussed with advanced optimizations.

### 2.3 Previous surveys on classical and swarm intelligence based routing protocols

In [25] authors presented a survey on classical and swarm intelligence based routing protocols. The review highlighted various WSN design features and routing measures. Routing protocols were classified by considering computational complexity, path establishment strategy, network structure, energy consumption methods. Survey mentioned the lack of standard methods for accurate comparison of routing protocols and also provided a comparison of some standard classical and SI based protocols.

In [26], basics of QoS support were discussed along with the necessity of QoS in each protocol layer. Different QoS-aware classical, swarm intelligence based protocols were discussed with their advantages and drawbacks. For each protocol, QoS parameters were compared to exhibit its performance. In order to enable QoS management effectively, the requirements and research issues of several computational intelligence (CI) methods were provided.

Table 1 shows the details of authors and their area of study.

Although, there are a good number of survey articles on classical routing protocols in WSNs whereas there exists comparatively a less number of survey articles on swarm intelligence category. This article is an effort to illustrate recent research and developments for hierarchical protocols in classical and SI category. It provides a comprehensive review on recent state of art hierarchical (classical and SI based) routing protocols reported from 2012 to 2017. Article emphasizes on analytical comparison of routing protocols considering various metrics such as energy efficiency, data aggregation, location awareness, QoS, scalability, load balancing, fault tolerance, multipath, query based. A detailed illustration of protocols classification, objective, methods, advantages and future scope has been presented. The review also highlights research challenges and open issues related to this domain. Finally, the new research directions have been proposed for future research in this domain.

## 3 Taxonomy of routing protocols classification in WSNs

In recent years, WSN have used many routing protocols for enhancing the network performance. The taxonomy of routing protocols classification is represented in Fig. 2.

These protocols are classified based on network structure and properties. The node uniformity has been used to categorize the network structure. The primary characteristic of these type of protocols is how nodes connect and transmit the data based on the framework of interconnections.

### 3.1 Structure-based routing

Network structure performs a significant role in the routing protocols. The fundamental element of this kind of routing protocols is the way nodes are associated and impart the data transmission based on the design of the network. Data-centric, hierarchical and location based are the arrangements of the structure based protocols [15, 19].

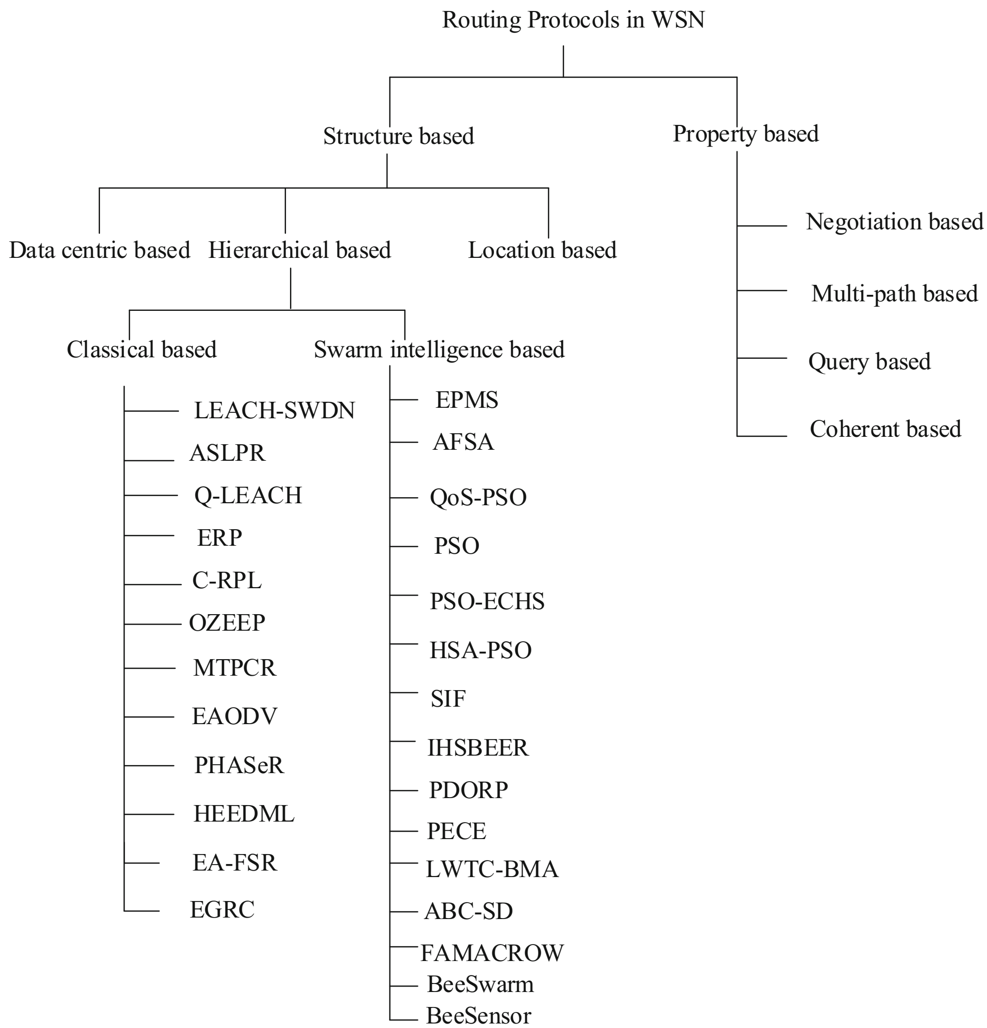
#### 3.1.1 Data-centric protocols

In data-centric communication when source node sends information to sink node, the intermediate sensors execute several structures of aggregation on the information created from multiple sources of the sensor network and transmit the aggregated information in the direction of sink. This process results in energy saving by eliminating redundant

**Table 1** Summary of previous surveys on hierarchical routing protocols

| S. no | Year of review | Authors | Category |
|---|---|---|---|
| 1 | 2012 | Zungeru et al. [25] | Classical and swarm intelligence |
| 2 | 2013 | Manap et al. [14] | Classical |
| 3 | 2013 | Pantazis et al. [15] | Classical |
| 4 | 2014 | Rault et al. [16] | Classical |
| 5 | 2014 | Saleh et al. [22]. | Swarm intelligence |
| 6 | 2015 | Liu [17] | Classical |
| 7 | 2015 | Tanwar et al. [18] | Classical |
| 8 | 2016 | Arora et al. [19] | Classical |
| 9 | 2016 | Jadhav and Satao [20] | Classical |
| 10 | 2016 | Anasane and Satao [21] | Classical |
| 11 | 2016 | Gui et al. [23] | Swarm intelligence |
| 12 | 2016 | Fei et al. [24] | MOO and swarm intelligence |
| 13 | 2017 | Asif et al. [26] | QoS aware classical and swarm intelligence |

**Fig. 2** A taxonomy of routing protocols classification in WSNs



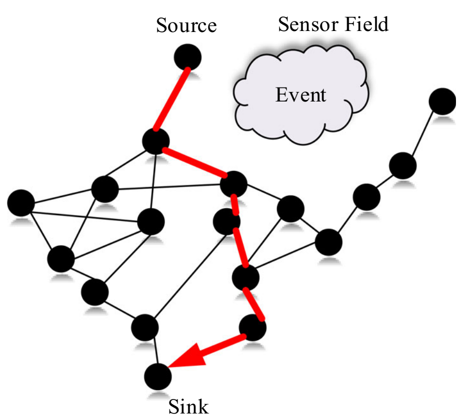




**Fig. 3** Data centric communication with minimum energy saving path

data. These type of protocols have limited memory storage for data caching. Figure 3 illustrates the data centric routing.

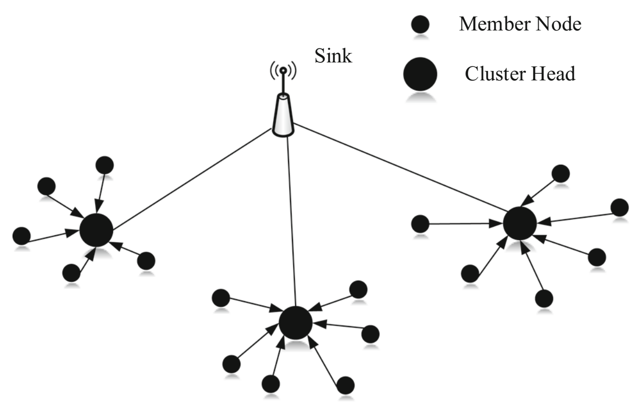



**Fig. 4** Hierarchical structure

### 3.1.2 Hierarchical routing protocols

In hierarchical routing protocol, the nodes are not identical and they perform various performance based functions. The nodes which have high energy level, can be used for processing and transferring the information. The nodes which have lower energy levels are used for sensing the information. These protocols have been further classified into classical and SI. The detailed descriptions are given in the subsequent sections. These protocols exhibit convenient topology management, high efficiency energy usage, simple data fusion, simple topology structure, less energy consumption, good load balancing and maximum network lifetime. Figure 4 illustrates arrangement of nodes and sink in hierarchical manner.

#### 3.1.3 Location based routing protocols

In location based routing SNs are identified by their geographic position. Location based protocols utilize this knowledge for calculating distance metric between SNs and their neighbors or SNs and sink. SNs location database makes it convenient for location based protocols to diffuse a query in a defined region which results in reduced number of transmissions, ultimately leading to energy saving.

### 3.2 Property based routing protocols

The operations of WSNs are classified as per their functionalities. The objective of property based routing is to attain optimum performance and protect the insufficient resources of the sensor network [19]. Negotiation based, multi-path based, query based, and coherent based routing protocols are classified under the property based routing protocols.

#### 3.2.1 Negotiation based routing protocols

The removal of transmission of redundant information by high-level data descriptors is the main aim of these protocols. The aim of negotiation based routing is to prevent the dummy data and control redundant information directed to the subsequent sensor network or BS by operating a list of negotiation messages ahead of the initiation of real data transmission.

#### 3.2.2 Multi-path based routing protocols

Sensor networks improve the performance by multiple pathways instead of a single path. If there is any interruption in the primary path, then an alternate pathway is established between the source and the destination node. The fault tolerance is enhanced by conserving multiple pathways between the sender and receiver node at the cost of network control packet overhead and consumed energy. Control messages are generated periodically to keep alternate paths alive. Therefore, it attains higher network reliability at the cost of higher network control traffic for preserving multiple pathways to the destination.

#### 3.2.3 Query based routing protocols

A query is initiated by receiver node for the information retrieval from the sender. High-Level languages are used to express queries over the network.

#### 3.2.4 Coherent based routing protocols

In coherent based routing protocol, the information is directed to aggregators after minimum processing. It normally covers time stamping, duplicate suppression etc. This coherent process is mainly used in the energy-efficient routing.

*The following observations have been made about various categories of routing protocols:*

It has been observed that hierarchical routing protocols have an edge over other categories for large networks because energy consumption and end to end delay is reduced to a great extent. Hierarchical network structure also provides good scalability and load balancing. However, the point of worry is issues associated with node connectivity and topology maintenance. Data centric protocols use redundant data elimination method to save energy and they are not well suited for large networks because of increased end to end delay, as data is sent by multi hop transmission. Data centric communication is good for small network scenarios. Control message overhead is reduced in location aware routing protocols which leads to lower energy consumption. It is possible due to region attributed query diffusion which lowers the number of transmissions. Location aware protocols have limited scalability especially while handling node mobility. Major point of concern with property based protocols is that they do not provide guaranteed data delivery due to lower throughput and delivery ratio.

## 4 Review on classical hierarchical routing protocols

Classical hierarchical routing protocols were principally designed for Mobile Ad hoc Networks (MANETs) [25]. However as per researcher's observations, it is a good match for WSNs as well, but it has some major constraints concerning energy and scalability. Clustering performs a critical role in saving the energy of sensor nodes. Effective utilization of sensor nodes energy is the central focus of cluster based routing in multi-hop communication. The SNs are energy constrained due to their limited battery power. The energy is depleted in SNs while transmitting the information from SNs to the base station. This section investigates a few typical hierarchical routing protocols based on classical (conventional) approach.

### 4.1 Protocol enhancements over LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH) is a classical and adaptive hierarchical routing protocol which considers mainly the energy consumption during its operation. Wang et al. [27] had proposed LEACH-SWDN (Low Energy Adaptive Clustering Hierarchy with Sliding Window and Dynamic number of Nodes) protocol for enhancing the LEACH outcome. In this protocol, the sliding window generates a random number to make an interval. Average energy of non-CH nodes and initial energy of nodes is utilized to calculate sliding window interval. The size of sliding window determines the selection probability of a CH and expected number of CH. The optimal cluster head is adjusted dynamically based on number of living nodes. Thus, the number of cluster heads are optimally placed and the energy is balanced with the reduced energy consumption in comparison to LEACH, ALEACH, LEACH-DCHS protocols. Shokouhifar and Jalali [6] had introduced an Application-Specific Low Power Routing (ASLPR) protocol which extends the network lifetime as per specified application. Due to complexity of control parameters of proposed algorithm it becomes extremely important to tune them. The hybrid optimization based on simulated annealing and genetic algorithm is utilized for optimizing control attributes which enhances the lifetime of network. The outcome of simulation gives enhanced lifetime and minimum utilization of energy compared to LEACH, LEACH-EP, LEACH-DT protocols. Manzoor et al. [28] proposed Quadrature-LEACH protocol for enhancing the throughput, stability period and network lifetime for homogeneous networks. Optimal clusters are formed by partitioning the network into four quadrants and further into subsectors which provides better node distribution. It solves the problem of higher energy depletion of farthest nodes in the cluster. Optimal clustering leads to good distribution of nodes in a particular field. This protocol achieves better coverage of the entire network and energy efficient operation in comparison to DEEC, SEP, LEACH protocols. Bara'a and Khalil [29] had proposed enhancements over LEACH protocol for providing the energy efficiency and improved stability period for heterogeneous sensor networks. Authors named it as ERP (Evolutionary Routing Protocol). Evolutionary Algorithm (EA) or meta-heuristic approach with modified fitness function is utilized to introduce compactness (cohesion) and separation error for improved clustering. Evolutionary approach function along with improved fitness function helps the protocol to achieve energy efficiency and better stability period than HCR protocol. ERP fails to achieve better stability period than SEP protocol whereas energy efficiency is better than SEP.

### 4.2 Cooperative routing protocol for low-power and lossy networks (C-RPL)

Advanced WSNs are used for performing various functions which execute different tasks like sensing, collecting the required information from various sensing areas and finally processing it. These heterogeneous data sets may require different processing functions as well. Hence, conventional tree-based routing will not suffice the job. The network is divided into numerous RPL instances in IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL). RPL does not explain any mechanism for selecting the node that belongs to an instance. Barcelo et al. [30] had developed Cooperative-RPL (C-RPL) protocol which is a collaborative and collected mechanism for creating several instances among the nodes. C-RPL facilitates the coordinated effort among RPL Instances. In C-RPL, the aim of each instance is to increase the performance with decreased energy consumption. In RPL, both the instances and their constructions operate independently from each other. The nodes belonging to each instance must be defined earlier to enhance the flexibility of routing procedure.

In C-RPL, predefining of nodes is not needed, as it is constructed according to the objective function of each occurrence, their locations, and particular system conditions. Using coalitions, a larger C-RPL instance maximizes the performance of the system but consumes a lot of power. A new fairness analysis is used in sensor networks for attaining good trade-off in terms of consumption of energy and performance using the cooperation parameter $\alpha$. Performance comparison of C-RPL and RPL with heterogeneous traffic is done using MATLAB. Simulations in MATLAB platform reveal that a better trade-off among performance parameters and energy efficiency is achieved in C-RPL protocol than the RPL protocol for heterogeneous traffic.

### 4.3 Optimized zone-based energy efficient routing protocol (OZEEP)

WSNs face some problems like connectivity, bandwidth usage, coverage of network and these problems may affect performance of the network. The clustering ensures network scalability but it requires careful setting up. Srivastava and Sudarshan [31] introduced the Optimized Zone-based Energy Efficient Routing Protocol (OZEEP). Two stages of clustering procedures are used in this algorithm. Fuzzy Inference System is used during the primary stage. This system uses Fuzzy Logic Controller (FLC) for selecting the CH by narrowing down on best nodes as contenders. FLC is comprised of fuzzifier, de-fuzzifier, fuzzy interference system, and fuzzy decision rules. The input specifications of the system include energy of each node, distance of the node from BS, node density and the mobility of each node. To promote the best node as CH, a genetic procedure is used. Furthermore, an ideal number of such CHs are computed in the system for acknowledging complete scope and hence adjusted further. The fuzzy module performs first level of screening which specifies nodes that can battle for becoming CH. In second stage genetic algorithm is applied which provides optimal balanced distribution of CHs. OZEEP achieves better energy efficiency and very less packet loss in comparison to ZEEP.

### 4.4 Minimum transmission power consumption routing (MTPCR)

The Received Signal Strength Indicator (RSSI) measure of a received packet and contentions occurred during MAC layer are two factors which can influence the transmission bandwidth. Chen and Weng [32] proposed Minimum Transmission Power Consumption Routing (MTPCR) protocol for power—aware routing. This protocol identifies the preferred pathway for routing which reduces the energy consumption. MTPCR protocol also considers that transmission bandwidth is decreased due to higher energy consumption in applications handling mobility of nodes. Power consumption analytics are obtained by maintaining neighboring nodes information. The bandwidth of good pathway is sustained by using a pathway maintenance mechanism. Node density is used to decide whether to activate pathway maintenance procedure or not. The simulation results give reduced power consumption and better network bandwidth than AODV, DSR, MMBCR, xMBCR, PAMP. MTPCR also reduce the breakages in pathways.

### 4.5 Extended ad hoc on-demand distance vector (EAODV) routing protocol

In this protocol WSN is assumed as a scale-free weighted network. Multicast communication minimizes bandwidth, cost, and energy. Zhang et al. [33] developed a multicast routing protocol based on Distributed Minimum Transmission (DMT) called Extended Ad hoc On-Demand Distance Vector (EAODV). Every sensor node has a similar communication range and fixed transmitting power. If the threshold of the received power is smaller than the accepted signal, then the data packets are successfully accepted. To provide route optimization solution EAODV protocol selects forwarding routes which connect multicast receivers. EAODV exhibits better performance in terms of package loss rate, delay, throughput and energy consumption as compared to AODV, LEACH protocols.

### 4.6 Proactive highly ambulatory sensor routing (PHASeR)

The robust and dynamic routing of data is enabled in mobile WSNs by several methods. Proactive Highly Ambulatory Sensor Routing (PHASeR) is a protocol proposed by Hayes and Ali [34] for the purpose of radiation mapping by unmanned automobiles.

As per proposed protocol, in mobile environments, a global TDMA MAC layer does not need any dynamic scheduling for sustained gradient measure. The blind forwarding method is used by this protocol to send messages in multipath manner. A stable time slot generates collision-free TDMA MAC layer. The cycle length is determined using the sensors sampling frequency, where there exists a predefined length for each time slot. Hop-count gradient is used to execute blind forwarding by PHASeR. All neighboring nodes hear about the communication and it is the receiving node which independently finalizes the need to send any received information further in the network based on hop count gradient value. The PHASeR method is mathematically analyzed for scalability, traffic load, and mobility. This protocol gives better performance measures for a wide range of applications. PHASeR shows reduced energy consumption in comparison to AODV, OLSR.

### 4.7 Multi-level hybrid energy efficient distributed clustering protocol (HEEDML)

Singh et al. [35] developed a hybrid energy efficient distributed clustering protocol (HEED), and this protocol is also called as Multi Level HEED (HEEDML). Residual energy and intra-cluster communication cost are the two parameters used for CH selection to improve the network life time in HEED. Residual energy is used for initial CH selection. When the range of a node falls in multiple CHs, there occurs a tie and intra cluster communication cost is utilized to remove this conflict. Distance and node density are two additional parameters used for CH selection procedure in fuzzy implementation. After CHs selection the data aggregation is performed and data is transferred through multi-hop transmission. In fuzzy logic based and non-fuzzy based implementations the protocol executions are illustrated as HEEDML-0/1/2/3/4. Protocol deals with five levels of heterogeneity for energy. The difficulty of imprecise data and uncertainties are easily handled using this method. The proposed protocol provides better performance in terms of total energy consumption, throughput, packet delivery, average delay, and transportation load in comparison to its earlier variants.

### 4.8 Energy-aware fisheye state routing (EA-FSR)

Kumar et al. [36] developed an Energy-Aware Fisheye State Routing (EA-FSR) protocol. The simulation is performed under different parameters using QualNet5.0. It considers energy as the basic parameter for selecting a neighboring node rather than distance. The energy of all the neighboring nodes is compared to find a node with highest remaining energy. An energy aware path selection algorithm is utilized along with basic FSR mechanism. Packets are forwarded using the nodes selected on the basis of the most efficient parameters of energy. Distance between nodes and sink is considered during this process. Protocol attains better performance with reduced energy consumption than FSR protocol.

### 4.9 EGRC (energy-efficiency grid routing based on 3D cubes) for UASNs

Wang et al. [37] have proposed a novel energy efficient protocol for reliable data transmission for environmental monitoring in Underwater Acoustic Sensor Networks (UASNs). Energy consumption is considered as one of the most challenging issue in underwater environmental monitoring applications like submarine oil pipeline monitoring. Therefore, authors proposed EGRC (Energy-Efficiency Grid Routing based on 3D cubes) for UASNs. EGRC considers complex attributes of underwater medium which are 3D dynamics of topology change, node density, node mobility, higher propagation delay and CH rotation mechanism.

The system is modeled as a big 3D cube which utilizes multi-hop architecture, MAC layer duty cycle mechanism to maintain sleep/wake up schedule for energy saving and an energy efficient routing protocol for network layer. 3D underwater network is configured as a collection of 3D Small Cubes (SCs) which are assumed as clusters. Node density depends upon size of SCs. EGRC proposes a novel cluster head selection approach on the basis of higher residual energy and smaller distance to BS. Further, a dynamic cluster head selection mechanism is introduced where SC's becomes cluster heads on rotation basis for a predetermined time period. An efficient search algorithm is introduced for next hop selection during optimal route construction which considers end to end delay, distance and energy metrics as selection parameters. Simulation of EGRC is performed on NS-2 with Aqua-Sim package which proves that EGRC exhibits an enhanced network lifetime and better energy efficiency in comparison to LEACH, EL-LEACH, ERP$^2$ R, VBF and L2-ABF protocols. EGRC also exhibits less end to end delay in comparison to VBF and L2-ABF protocols.

*The following observations have been made from reviewed classical hierarchical routing protocols*

Optimum selection of CHs with respect to number of SNs, is the ideology of LEACH-SWDN to conserve energy whereas the compromising factor is the increased network load due to control packet overhead in each round. However, authors insist that it has a nominal effect on network performance. The novelty of ALSPR lies in extending the network lifetime based on specific application by optimizing control attributes using Genetic Algorithm and Simulated Annealing. However, protocol fails to deal with large scale network topologies. Q-LEACH achieves better network coverage and energy efficiency through optimal distribution of SNs by performing optimized sub sectoring using randomized clustering algorithm. Q-LEACH needs further enhancements to deal with mobility in dynamic network scenarios. ERP approach function and improved fitness function (cohesion, separation) leads to balanced clustering mechanism which in turns provides energy efficiency for heterogeneous networks. However, ERP fails to achieve better stability period than SEP. C-RPL protocol achieves an optimum balance between performance parameters and network energy efficiency than RPL. Future enhancement of the protocol is required to implement its operation in decentralized network scenarios. OZEEP protocol is better a choice for real time applications and deals with SNs mobility as well. It achieves higher energy efficiency, low packet drop rate than ZEEP. MTPCR utilizes an optimal path discovery and maintenance mechanism which provides improved transmission bandwidth and reduced path breakages. It is a good choice for mobility based applications. EAODV protocol provides QoS awareness and handles mobility of SNs. However, robustness of protocol needs further enhancement. PHASeR protocol can effectively handle mobility in dynamic network scenarios. It is well suitable for applications like radiation mapping by unmanned vehicles. PHASeR shows robust operation as well. HEEDML provides very high energy efficiency by utilizing fuzzy and non-fuzzy implementations of protocols. Protocol enhancements are required to handle mobility in dynamic environments. EA-FSR fails to deliver in high mobility based applications. EGRC protocol is the best choice for applications requiring reliable and energy efficient data transmission in UASNs.

## 5 Review on swarm intelligence based hierarchical routing protocols

Swarm intelligence based protocols have an essential idea of self-association, self-organization which incorporates positive feedback, negative feedback and cooperative behavior in decentralized manner. Ant colony optimization

(ACO) [38, 39], particle swarm optimization (PSO) [22], bee colony optimization (BCO) [24] are various SI based meta-heuristic algorithms used for routing. In ACO, the activity of laying pheromone by ants is a real feedback instrument to enroll more ants with the end goal that more pheromone is arranged on the shortest path to destination. Additionally, ant uses an indirect coordination mechanism called stigmergy which is utilized in the combined problem-solving practices. The ants have a nature of leaving pheromone, a compound substance, which is left for other ants to perform their stigmergic communication.

PSO is one of the swarm intelligence approach in which swarm is represented as a group of particles. During transmission, the swarm will move in the search space to discover the minimum distance path. Each particle has current position, pbest (personal best) position, gbest (global best) position and velocity. Current position specifies the position of a particle in current time. Pbest represents the best position of each particle till that time. Gbest is the best position of any particle among all in search space. The velocity means the personal velocity of each particle. In this algorithm, each and every particle tries to move towards the particle having solution. If movement is completed by following the particle having solution, that is considered as an optimal solution.

In artificial bee colony (ABC) [24], the possible solution for routing is the position of food source and quality corresponds to the nectar amount. There are three kind of bees which are employed bees, onlooker bees, scout bees and they are used to solve the optimization problem. The food source count is equal to the number of employed bees. So every employed bee has a food source around the hive. Onlooker bees continuously keep an eye on the dances of employed bees and select food source accordingly. Scout bees appear if the food source of employed bees is forbidden. There are a number of protocols proposed by the researchers with the help of the swarm based optimization algorithms. A few of those protocols are discussed below.

### 5.1 Energy efficient PSO based routing algorithm with mobile sink (EPMS)

Wang et al. [40] introduced a clustering algorithm based on particle swarm optimization using a portable sink. Virtual clustering and PSO is collectively used in EPMS to attain energy efficient operation. A virtual clustering method utilizes information about a node's location and residual energy parameters of SNs to find CHs. EPMS routing algorithm defines three formats of data packets which are Hello packet, Message-s packet, and Message-h packet. The Hello packet is used to find which cluster area has sent information to the mobile sink. Message-h packet is used for sending information to the cluster head. Finally, Message-s packet is used for sending information to the sink node. The simulation results exhibit that energy consumption of the overall network has decreased to almost 12%, ensuring longer network lifetime than LEACH, TTDD. However, there is only a slight improvement in the jitter values and end-to-end delay.

### 5.2 Artificial fish swarm algorithm (AFSA)

Helmy et al. [41] developed a hierarchical routing protocol called Artificial Fish Swarm Algorithm (AFSA) which is a SI based optimization protocol for minimizing the usage of energy and enhancing the network lifetime. This approach selects the optimum CH by using Preying, Swarming and Following. A fitness function is utilized to select a better CH based on the swarm behavior. Simulation results in MATLAB show that the protocol exhibits energy efficient operation in comparison to LEACH and PSO.

### 5.3 PSO based routing algorithm

Liu et al. [42] proposed a QoS based agent-assisted routing algorithm QoS-PSO. In this algorithm, synthetic QoS is selected and this QoS is an adaptive value of PSO algorithm for enhancing the entire network performance. The flow of network communication, routing state of each node and network topology changes were examined by intelligent software agents. These agents were used for network maintenance and routing. QoS-PSO protocol exhibits excellent QoS measure for latency and packet loss in comparison to AODV, EEABR. The protocol performance is better for larger networks in terms of scalability whereas network control packet overhead is raised with large route discovery.

Kuila and Jana [43] found solution for two most commonly known optimization problems which are energy efficient routing and clustering. Authors presented linear and non-linear formulations for these two important optimization problems using PSO algorithm. Efficient particle encoding scheme with its multi-objective fitness function is better suited for routing and clustering solution using weighted sum approach. A routing trade-off is created between delay in forwarding data packets and transmission distance. PSO based optimization algorithm selects a route from all the gateways to base station which has comparatively lower overall distance as well as less number of data forwards. The encoding scheme and the multi-objective fitness function is applied using weighted sum approach. The protocol exhibits a better performance for total data sent to BS, network lifetime, inactive SNs in comparison to GAR, MHRM protocols.

Rao et al. [44] implemented a PSO based Energy efficient Cluster Head Selection algorithm (PSO-ECHS). The fitness function and particle encoding are used in PSO-

ECHS. Selection of cluster head is done by considering various parameters like sink distance, residual energy and intra-cluster distance to calculate weight function which leads to energy efficient operation of protocol. The protocol attains better performance for network lifetime and energy consumption in comparison to LEACH, LEACH-C, E-LEACH.

Shankar et al. [45] had developed an energy efficient hybrid Harmony Search Algorithm (HSA) and PSO based algorithm known as HSA-PSO. CH selection is based on the criteria of distance and residual energy. This algorithm attains better convergence and higher search efficiency. In HSA-PSO, it first initializes the network parameters and assigns values to velocity, position of particle fitness function and hybrid matrix. These parameters describe Particle Harmony Memory (PHM). PHM generates a new improved harmony. An update about hybrid harmony memory, particle position and velocity is maintained. The hybrid HSA–PSO algorithm achieves better network lifetime, FND, LND, standard deviation values than LEACH, HSA, PSO.

### 5.4 Swarm intelligence based fuzzy routing protocol (SIF)

The sensor nodes are battery powered and it is hard to exchange or recharge the battery. Zahedi et al. [46] developed an SI-based fuzzy routing protocol (SIF). There are two basic steps in setup phase: Cluster formation and CH selection. The entire network is divided into clusters using fuzzy c-means algorithm, which is relied upon to accomplish a balanced cluster with a worthy distribution of CHs throughout the system. A priority factor (PF) is computed after cluster framing by using Mamdani fuzzy framework to choose the CH. Three factors are considered in the SIF as fuzzy data sources which are distance from cluster centroid, distance from the BS and residual energy.

This scheme finds the required number of groups needed in the network for clustering and reduces the sum of distance between cluster centers and instances. The performance of the fuzzy scheme is affected by applying fuzzy rules. A hybrid swarm intelligence algorithm is developed for optimizing the fuzzy rule base by utilizing the concept of simulated annealing and firefly. This hybrid swarm intelligence algorithm performs balanced clustering to achieve minimum overall energy consumption than LEACH, LEACH-FL, LEACH-DT, ALSPR.

### 5.5 Predictive energy consumption efficiency (PECE) routing technique

Zhang et al. [47] introduced predictive energy consumption efficiency (PECE) based routing technique. In this technique, the proposed work is divided into cluster formation phase and stable data transfer phase. In the first phase, residual energy, degree of a node and distance between the nodes are used as parameters for CH selection. In the next phase of multi-hop data forwarding, PECE is structured by bee colony optimization. The routing pathway is computed by considering the energy consumption values, hop count, delay measure from source to sink node. Optimization structure of algorithm enhances the cluster quality and network performance by reducing power consumption and achieves the enhanced coverage as well. It prolongs the network lifetime in comparison to traditional clustering algorithm LEACH, PEGASIS.

### 5.6 Improved harmony search based energy efficient routing algorithm (IHSBEER)

Zeng and Dong [48] proposed IHSBEER protocol. The harmony search algorithm has a simple concept and strong global search capability. The important stages of traditional HS algorithm are initializing the algorithm parameters, initialization of harmony memory (HM), improvising harmony memory, update the HM and repeat till termination condition is met. The continuous optimization problem is solved using this algorithm but WSN routing is a discrete optimization issue because of uncertain behavior of SNs. So, the traditional HS algorithm is not useful for addressing routing problem of WSNs. Moreover, a number of improvements are needed in traditional HS algorithm in accordance with attributes of routing problem. In harmony search algorithm, the pathway to forward the message from a source to sink is denoted as harmony. Initially, the enhancement to the encoding of HM is proposed as per the attributes of WSN routing. Next, the dynamic adaption avoids prematurity and supports local search capability. Lastly, an efficient local search approach for improving the local search capability, accuracy, and convergence speed of routing algorithm was applied. The protocol achieves enhanced network lifetime in comparison to EEABR, ACORC, EEHSBR protocols.

### 5.7 PEGASIS-DSR optimized routing protocol (PDORP)

Energy consumption is the most significant factor in WSN. The routing protocols are used to find a solution to the issues associated with energy efficiency and Quality of Service (QoS). Dynamic Source Routing (DSR) protocol enhances the network performance by utilizing sleep/wake up scheduling mechanism. It leads to reduced energy consumption. However it increases the waiting time. Brar et al. [49] had developed an energy aware routing protocol mentioned as PDORP with a directional transmission. This protocol has the features of both DSR and PEGASIS routing protocols, and the optimal pathway of routing is identified by hybridization of Bacterial Foraging Optimization (BFO) and GA (Genetic Algorithm).

The sensor nodes are deployed arbitrarily and node distance from neighboring nodes is calculated and compared with a threshold value. The optimal route is selected in the large coverage set of nodes using path finding algorithm. The proactive and reactive qualities of routing model are used in PDORP. To attain the better results of QoS and increased network lifetime, an advanced hybridization technique is used. The hybrid features of BFO and GA are utilized in PDORP to achieve better QoS measure and enhanced network lifetime.

### 5.8 Light weight trust based secure and energy efficient clustering using honey bee mating algorithm (LWTC-BMA)

The procedure of honey bees mating is a swarm intelligence based technique, where the search algorithm simulates the true honey bees mating process. Sahoo et al. [50] developed LWTC-BMA protocol which utilizes a model of pragmatic energy consumption used for evaluating the network lifetime. This protocol is divided into Cluster setup and steady state phases. CH selection is carried out in set-up phase. Protocol builds up a trust method to avoid any malicious node to become a CH. The system discovers trustworthy and energy efficient cluster head. The steady-state phase is utilized for multi-hop data forwarding. This protocol performs better in terms of a total energy consumption, alive nodes, average residual energy in comparison to LEACH, TCBMA protocols.

### 5.9 Cluster based artificial bee colony (ABC-SD) routing protocol

Ari et al. [51] developed a cluster based power efficient routing protocol named as ABC-SD. This protocol utilizes search features of artificial bee colony (ABC) which is used to design the low power consumption cluster. A Linear Programming formulation which utilizes a multi objective fitness function is accomplished at the sink using centralized control mechanism. The fast convergence characteristics and efficient features of meta-heuristic ABC are used for building clusters. The choice of CHs in clustering defines routes for inter-cluster communication. A trade-off between energy and hop count is taken to compute cost based measure for optimal routing path selection. The ABC-SD technique is evaluated with various technologies in different network sizes and results illustrate the efficiency of protocol based on coverage, packet delivery ratio and network lifetime. It is better than PSO-C, LEACH-C, LEACH, ABC-C protocols.

### 5.10 Fuzzy and ant colony optimization based combined mac routing an unequal clustering cross-layer protocol (FAMACROW)

Gajjar et al. [52] proposed Fuzzy and ACO based FAMACROW protocol for energy efficient routing. This protocol has network setup, neighbor search and steady-state mode of operation. In the network setup phase, all the nodes in the sensing area are arranged into layers. During neighbor discovery each and every node will transmit the NODE_DETAILS message using CSMA MAC whose signal strength is sufficient to communicate with all neighboring nodes in that layer. The distance of a node from its neighbor is computed by finding absolute difference of distance of a node to MS and distance of neighboring node to MS. The protocol utilizes fuzzy logic with remaining energy, link quality, neighboring node parameters for CH selection. After the steady state phase, neighbor finding stage is repeated to create FAMACROW protocol immune to link or node break down. Ant Colony Optimization is used in the FAMACROW for efficient and reliable routing identification from CH to MS. The hot spot problem affecting the permanent sink node is overcome by unequal clustering and artificial intelligence. The protocol shows better energy efficiency, throughput, network settling time and latency than IFUC, EAUCF, UCR, ULCA protocols.

### 5.11 Bee swarm based protocols

In hierarchical WSN, CH utilizes maximum energy because of the overload of information from SNs. Mann and Singh [53] introduced a BeeSwarm protocol containing three stages which are BeeCluster construction, BeeSearch for finding route, BeeCarrier for data transmission. BeeCluster, BeeSearch, BeeCarrier add to the robustness of protocol. The cluster construction is performed by executing CHs selection and formation procedure. In the setup phase, first the CH is selected using ABC meta-heuristic. After the selection of CH, the formation of clusters is done. A join request is transmitted to all the neighboring nodes from the CH to form the clusters. The BeeSearch phase determines the routes for communication through scout bees. This is carried through forward and backward search procedures. The network is examined through the forward search. The pathway among various nodes and BS is created and maintained in the backward search approach. BeeSwarm enhances the lifetime of the network by 10–15% in comparison to MRP, ERP. Saleem et al. [54]

introduced a bee-inspired protocol called as BeeSensor. This protocol uses Bee agent model, agent to agent communication to find optimal paths and enhances the performance of protocol. The protocol exhibits better results in terms of PDR, latency minimum energy utilization and network lifetime.

*The following observations have been made from reviewed SI based hierarchical routing protocols*

EPMS protocol utilizes virtual clustering concept along with particle swarm optimization and achieves energy efficiency. However, it is not suitable for real time applications. AFSA protocol lacks QoS awareness and needs further improvements to handle mobility. QoS-PSO algorithm is a better choice for real time applications as it provides excellent QoS measure. However, protocol needs further improvement to effectively handle high mobility in dynamic scenarios. QoS-PSO exhibits very good scalability for large network topologies. PSO protocol requires further enhancements to handle mobility in dynamic network scenarios. PSO-ECHS protocol exhibits high energy efficiency. However, future enhancements are required for heterogeneous networks. HSA-PSO achieves high energy efficiency and better convergence. HSA-PSO protocol needs improvement in terms of scalability for large scale networks. SIF exhibits application specific behavior as it can be optimized as per nature of application to extend network lifetime. However, protocol enhancement is required for handling sink/SNs mobility. PECE protocol performs optimal clustering which leads to balanced energy consumption as well as enhanced network lifetime. The limited scalability of protocol is still a concern. Performance of IHSBEER protocol is unmatched for small size networks and it is a better choice for applications like industrial monitoring and control, body area networks, smart homes etc. However, in large scale WSN an undesired situation may arise in which forward paths of SNs are through sink. The hybrid features of PEGASIS, DSR along with Genetic algorithm and BFO optimization in PDORP achieves better QoS and energy efficiency. PDORP protocol is well suited for real-time applications. LWTC-BMA protocol needs further enhancements to handle mobility aspect for dynamic network scenarios and its performance for very large scale networks still needs to be explored. ABC-SD protocol exhibits high energy efficiency and QoS measure. It is a good choice for real time applications. FAMACROW protocol provides a better solution to hot spot problem using unequal clustering and ACO. BeeSwarm protocol needs application specific implementation on real test beds. The scalability of BeeSensor is required to be validated for large scale networks.

Table 2 shows the main characteristics of the different classical and SI based hierarchical routing protocols.

## 6 Open issues and challenges affecting the energy efficient hierarchical routing design

The construction of routing protocols is affected by different challenging aspects. The effective communication is achieved by overcoming these challenges. This section describes various routing and design challenges before we highlight open issues.

*Restricted energy capacity* Sensor nodes have limited battery power and they are randomly positioned in the difficult regions. Mostly, it is quiet difficult to recharge the battery or to exchange the dead battery.

*Data Aggregation* To effectively utilize network bandwidth, redundant data packets generated by SNs are required to be aggregated which results in reduced data size and less communication load. Data aggregation is the collection of data from various sources and it is performed with the help of suppression, max, min, and average operations.

*Scalability* Routing protocols designed must have the capability to scale up with the size of the network. A trade off should be maintained between scalability and latency measure of a protocol.

*Network Dynamics* The topology of a WSN keeps on changing repeatedly because of sensor addition, node failures and energy depletion. Moreover, the SNs are connected by a wireless medium, and this medium is noisy, fault prone, and time bound. So, pathways for routing must reflect good network performance dynamics.

*Delay* It is an utmost important factor for time bound/-time critical applications. Real time applications require information to be sent immediately in a time bound manner else it will be of no use. So, the delay control is the primary objective of the routing protocols in the network.

*Limited hardware resources* The storage abilities, computational functionalities and processing capability of SNs is limited. Due to hardware restrictions, there is a need for better design of network protocols and software algorithms.

*Fault Tolerance* Physical damage and intrusion of environment results in failure of SNs. These defects in SNs should not disrupt the WSNs operation. Fault tolerance is the capability to keep functionalities of the network running without any disruption due to sensor node failures.

*Data Delivery Model* This model is used to find how the information is composed and delivered. The data delivery model may be continuous, query-driven, event-driven, and hybrid. In the continuous delivery model, every sensor transmits information periodically. In query-driven model, the data transmission is activated when sink generates the query. In event-driven model, when an event occurs the

**Table 2** Relevant literature on classical and swarm intelligence based hierarchical routing protocols

| Protocols | Classification | Objective | Methods | Advantages | Future scope | Metrics | Simulator |
|---|---|---|---|---|---|---|---|
| LEACH-SWDN [27] | Classical | To discover optimal cluster head count dynamically and energy efficiency | Optimal sliding window, dynamic optimization of CHs | Balanced and reduced energy consumption per round, enhanced network lifetime | To improve increased network load due to control packet overhead | Network life time, energy consumption, dynamic optimal CH count, success rate | NS2 |
| ASLPR [6] | Classical | To achieve enhanced network lifetime and balanced energy consumption of SNs | Hybrid genetic and simulated annealing, multi objective fitness function | Enhanced network lifespan, balanced energy consumption | To achieve multi-hop routing in large network topologies, to handle mobility of SNs | FND (first node dies), HND (half node dies), LND (last node dies), success rate | MATLAB |
| Q-LEACH [28] | Classical | To achieve a better stability period, enhanced network lifetime and coverage | Optimal clustering by applying randomized clustering concept | Improved network coverage and energy efficient operation | Protocol enhancement for large-scale networks and to handle mobility | Stability period, network life time and throughput | MATLAB |
| ERP [29] | Classical | To achieve longer network lifespan and enhanced stability period for heterogeneous networks | Evolutionary approach with modified fitness function (cohesion, separation) | Improved clustering and better energy efficiency, better stability period | Needs more improvement in fitness variant to prolong stability period | Average remaining energy of nodes, FND, LND, alive nodes | MATLAB |
| C-RPL [30] | Classical | To attain better network energy consumption and a fair network performance | A cooperative strategy and cooperative parameter $\alpha$ | Trade-off between energy consumption and network performance is achieved, avoid congestion and provides QoS measure | C-RPL implementation for distributed network scenarios | Average number of hops, average expected number of transmissions (ETX), average packet delivery ratio, average energy consumption | MATLAB |
| OZEEP [31] | Classical | To achieve optimal clustering, energy efficiency, fault tolerance, scalability | Genetic fuzzy system for optimal CHs selection | Reduced energy consumption, handles mobility aspect and good for time driven applications | Issue of re-clustering of disconnected nodes to join a CH in next round | Network lifetime, packet drop rate | MATLAB, NS2 |
| MTPCR [32] | Classical | To reduce power consumption, avoid network path breakages and to improve transmission bandwidth | Optimal path discovery algorithm, path maintenance mechanism | Better network bandwidth and enhanced network lifetime than AODV, DSR, MMBCR, xMBCR, PAMP | Enhancements for QoS awareness | Control packet overhead, power consumption, hop count, average hop length, throughput, path breakage count, network connectivity | C++ |
| EAODV [33] | Classical | To ensure both energy efficiency and network performance | Multicast tree optimization, distributed minimum transmission | Achieves enhanced network life time and performance | Promote the robustness | Energy consumption, delay, throughput, package loss rate | NS2 |

**Table 2** (continued)

| Protocols | Classification | Objective | Methods | Advantages | Future scope | Metrics | Simulator |
|---|---|---|---|---|---|---|---|
| PHASeR [34] | Classical | To enable the mobility and robustness factor in routing | Blind forwarding, gradient maintenance measure | Low overhead and better network performance | To analyze the effects of channel fading | Energy consumption, packet delivery ratio, average packet delay, throughput, control overhead, average end–end delay | OPNET |
| HEEDML [35] | Classical | To enhance the network lifetime and performance for heterogeneous networks | Fuzzy and non-fuzzy based implementations | Increase in network lifetime, PDR and low control overhead | Enhancements to handle dynamic networks | Packet delivery ratio, total energy consumption, throughput, average delay, and network traffic overhead | MATLAB |
| EA-FSR [36] | Classical | To ensure the reduction in overall energy consumption | Improved fisheye state routing, energy aware route selection | Ensure longer lifetime and decreased energy consumption | Enhancement needed for high mobility based applications | Average energy consumption, end-to-end delay, and throughput | QualNet 5.0 |
| EGRC [37] | Classical | To enhance reliability and energy efficiency in UASNs | Optimal clustering and active/sleep duty cycle mechanism | Lower end to end delay, enhanced network life time and energy efficiency | Application of EGRC protocol for industrial plants needs further enhancement and validation | Average residual energy, % age of Alive nodes, end to end delay, FND, LND, HND | NS 2 with aqua-Sim |
| EPMS [40] | SI | To achieve energy efficiency and better network performance | Virtual clustering, PSO | Energy efficient operation and improvement in average delay and jitter | QoS awareness | Energy consumption average delay and network lifetime | MATLAB |
| AFSA [41] | SI | To lower down network energy consumption | Optimized CHs selection using artificial fish swarm algorithm | Achieves better network lifetime. less energy consumption per round | Further validation of results in NS2 | FND, energy consumption per round, network life time, data received by BS | MATLAB |
| QoS-PSO [42] | SI | To enhance the QoS level | PSO based multi agent model | Improvement in the QoS measure | Improvement to effectively handle high mobility | Packet loss, average residual energy, QoS, mean delay | NS 2 |
| PSO [43] | SI | To extend lifetime of wireless sensor networks | PSO encoding, multi-objective fitness function, load balanced clustering | Energy consumption is balanced and network lifetime is improved | Enhancement to deal with dynamic network scenarios | Network life time, energy consumption, FGD (first gateway dies), LGD (last gateway dies), delivery of total data packets | MATLAB |
| PSO-ECHS [44] | SI | To attain enhanced network lifetime by conserving the energy of SNs | PSO, fitness function, weight function based balanced clustering | Better performance in terms of total energy consumption, network lifespan and success rate | Fault tolerance and heterogeneous networks | Total energy consumption, network life time | MATLAB |
| HSA-PSO [45] | SI | To attain balanced energy consumption among SNs | Hybrid harmony search and PSO | Achieves better search, convergence, energy efficient operation | Scalability enhancement for very large networks | FND, LND, residual energy, mean throughput, standard deviation | MATLAB |

**Table 2** (continued)

| Protocols | Classification | Objective | Methods | Advantages | Future scope | Metrics | Simulator |
|---|---|---|---|---|---|---|---|
| SIF [46] | SI | To achieve balanced clustering and minimum overall energy consumption | Fuzzy c-means, hybrid FA-SA (firefly and simulated annealing) | Energy efficient and avoid uncertainties during network operation | To extend the work for large scale topologies and with mobile sink/SNs | Maximum and standard deviation of intra-cluster distance, FND, HND, LND, success rate, round history of dead nodes | MATLAB |
| PECE [47] | SI | To prolong network lifetime, balanced energy consumption | Bee colony optimization, optimal clustering | Optimal cluster formation leads to enhanced network performance and balanced energy consumption | Scalability of algorithm needs to be enhanced | Network lifetime and remaining energy | OMNeT++ |
| IHSBEER [48] | SI | To enhance the network lifespan | Improved harmony search algorithm | Enhanced network lifetime and reduced energy consumption | To enhance scalability a new model to implement on NS3 for large scale networks, QoS awareness | Network life time, average residual energy, minimum residual energy, standard deviation of residual energy | C++ |
| PDORP [49] | SI | To enhance the network lifetime and improved QoS measure | Hybrid optimization using GA and BFO, hybrid features of PEGASIS and DSR, cache DSR integration | Reduced network control overhead, fast response, good connectivity of SNs, energy efficiency | Needs enhancement for dynamic environments | Throughput, delay, and bit error rate, energy consumption | MATLAB |
| LWTC-BMA [50] | SI | To present a trust based secure and energy competent clustering | Honey bee mating | Enhanced network lifetime | Enhancement for handling mobility | total energy consumption, alive nodes, average residual energy | MATLAB |
| ABC-SD [51] | SI | To design low-power scalable network and to improve energy efficiency | ABC, cost based function | Improved network lifetime, coverage, packet delivery ratio | Enhancement to deal with mobility, variable packet TDMA frame design | Energy consumption, energy efficiency, first sensor dead, amount of packet delivered, packet loss rate and network coverage | OMNeT++ |
| FAMACROW [52] | SI | To increase energy efficiency and network lifetime | Unequal clustering, fuzzy logic and ACO | Energy efficient, good scalability | To handle mobility and to add QoS awareness | Throughput, goodput, network settling time, and latency, FND, HNA, LND | MATLAB and NS2 |
| BeeSwarm [53] | SI | To design and develop power aware protocol | ABC meta-heuristic, optimal clustering | Enhanced PDR, and energy Efficiency | Application specific implementation on real test bed | Packet delivery ratio, average energy consumption, and throughput | NITSS: a java based platform |
| BeeSensor [54] | SI | To develop power-aware, scalable and performance efficient routing | Bee agent model, agent to agent communication | Least energy consumption, fault tolerant behavior | Enhancement to handle mobility, implement BeeSensor on TOSSIM, scalability validation | Latency, PDR, energy efficiency, lifetime, and control-overhead | MannaSim |

transmission of data is triggered. Some networks employ a hybrid model by utilizing a combination of event-driven, continuous, and query-driven models.

*The quality of Service (QoS)* It means the quality of services required by an application. It could be the length of a error rate, protection, data consistency, transit delay etc. These factors affect the choice of routing protocols for a particular application.

*Open Issues related to design and development of energy efficient routing protocols*

- Design and development of QoS aware routing protocols in energy constraint environment for real time applications, multimedia services is still an area which needs a lot of attention. It is realized from review that there are very few protocols available in this category. Issues related to delay and guaranteed bandwidth are required to be addressed in QoS aware routing protocols.
- Ability of routing protocols to handle mobility of SNs is still an area which lags. Assumptions which are made about static sink and SNs are not a real life scenarios. Military surveillance monitoring, target tracking in battlefield and intrusion detection applications require mobility aspect to be explored to handle SNs and sink mobility. Mobility of SNs and mobile sink poses another challenge of topology management/maintenance, connectivity of nodes which needs to be researched further in an energy constrained environment.
- A lot more emphasis is required for the design and development of application specific routing protocols. Designing application specific protocols will provide lot more acceptability of researched work and support its multi-dimensional aspects.
- It is realized from review that mathematical modeling of designed protocol is another area of concern which needs to be worked upon. To make a fair comparison between standard protocols, simulation task is required to be complemented with mathematical modeling to get a broader perspective of protocol.
- Implementation of routing protocols on real test beds/hardware is still one of the biggest open challenge. Development of routing protocol by using simulation tools may not explore certain aspects of algorithm which can be better checked on real hardware platform. Moreover, hardware may set some limitations on certain parameters which may not be possible to check on a simulator. However, the cost of hardware platform is a point of concern.
- Application specific research proposals are required to be made by researchers to get an approval from research organization so that inventions and a fruitful research can be carried out in this area.

## 7 Performance evaluation metrics of routing protocols

This section discusses various performance metrics of routing protocols to evaluate the performance. The parameters are chosen to make an effective evaluation of the performance characteristics of routing protocols.

*Throughput* It is measured as a number of bits transferred per second. The unit for measurement of throughput is Kbps (Kilobits per second). This measurement gives a quick thought of the productivity of system activity bolstered by each group. A higher throughput demonstrates that the framework sustained better steering for information and control messages.

*End to end delay* It is the time period taken by a standard system for transmission of packets from a sender node to destination node.

*Normalized routing overhead* Number of routing packets transmitted per data packet is defined as normalized routing overhead.

*Packet delivery ratio* It is defined as a number of packets received by destination node divided by the number of packets sent. It's unit of measurement is percentage (%).

*Latency* The delay in time during the transmission of data from sender to destination is referred as latency. It is measured in seconds.

*Success rate* The percentage of reception of entire packets at the receiver divided by the number of entire data packets generated in the network by the nodes. It is measured in percentage (%).

*Energy Consumption* It is defined as total energy consumed by nodes in the network when the experiment is conducted. Its unit of measurement is Joules (J).

*Energy Efficiency* It is measured as a ratio of total packets delivered at the destination node to total energy consumed by sensor nodes. It is mentioned in percentage Kilobits per Joule (Kb/J).

*Standard Deviation* Standard deviation is the average variation among the energy levels of entire network SNs.

## 8 Summary and analytical discussion on energy efficient hierarchical routing protocols

This section provides detailed summary and analytical discussion on energy efficient hierarchical routing protocols based on various performance metrics as shown in Table 3. The performance features considered for comparison are energy efficiency, data aggregation, location awareness, QoS, scalability, load balance, multipath, query based.

**Table 3** Summary of various hierarchical routing protocol

| Routing protocol | classification | Energy efficiency | Data aggregation | Location awareness | QoS | scalability | Load balance | Fault tolerance | Multi path | Query based |
|---|---|---|---|---|---|---|---|---|---|---|
| LEACH-SWDN [27] | Classical | Good | Yes | No | No | Limited | Yes | No | No | No |
| ASLPR [6] | Classical | Good | Yes | No | No | Moderate | Yes | Yes | Yes | No |
| Q-LEACH [28] | Classical | Good | No | Yes | No | Limited | Yes | No | No | No |
| ERP [29] | Classical | Good | Yes | No | No | Limited | Yes | No | No | No |
| C-RPL [30] | Classical | Good | Yes | Yes | Yes | Moderate | Yes | No | No | No |
| OZEEP [31] | Classical | Very good | Yes | Yes | Yes | Very good | Yes | Yes | Yes | Yes |
| MTPCR [32] | Classical | Very good | No | No | No | Very good | Yes | Yes | Yes | Yes |
| EAODV [33] | Classical | Good | Yes | No | Yes | Limited | Yes | No | No | Yes |
| PHASeR [34] | Classical | Good | Yes | Yes | No | Very good | Yes | Yes | Yes | No |
| HEEDML [35] | Classical | Very good | Yes | Yes | No | Limited | Yes | No | No | No |
| EA-FSR [36] | Classical | Good | No | Yes | No | Good | Yes | No | No | No |
| EGRC [37] | Classical | Very good | Yes | Yes | No | Good | Yes | Yes | Yes | No |
| EPMS [40] | Swarm intelligence | Good | No | Yes | No | Limited | Yes | No | No | No |
| AFSA [41] | Swarm intelligence | Good | Yes | Yes | No | Good | Yes | No | No | No |
| QoS-PSO [42] | Swarm intelligence | Good | No | No | Yes | Very good | Yes | Yes | Yes | No |
| PSO [43] | Swarm intelligence | Good | yes | No | No | Good | Yes | No | No | No |
| PSO-ECHS [44] | Swarm intelligence | Very good | Yes | No | No | Good | Yes | No | No | No |
| HSA-PSO [45] | Swarm intelligence | Very good | Yes | No | No | Moderate | Yes | No | No | No |
| SIF [46] | Swarm intelligence | Good | Yes | Yes | No | Limited | Yes | No | No | No |
| PECE [47] | Swarm intelligence | Very good | No | No | No | Limited | Yes | Yes | Yes | No |
| IHSBEER [48] | Swarm intelligence | Very good | No | No | No | Moderate | Yes | No | No | No |
| PDORP [49] | Swarm intelligence | Good | Yes | No | Yes | Very good | Yes | No | No | No |
| LWTC-BMA [50] | Swarm intelligence | Good | Yes | No | No | Good | Yes | No | No | No |
| ABC-SD [51] | Swarm intelligence | Very good | Yes | No | Yes | Good | Yes | No | No | No |
| FAMACROW [52] | Swarm intelligence | Very good | Yes | No | No | Very good | Yes | No | No | No |
| BeeSwarm [53] | Swarm intelligence | Very good | Yes | No | No | Limited | Yes | No | No | No |
| BeeSensor [54] | Swarm intelligence | Good | Yes | No | No | Moderate | Yes | Yes | Yes | No |

### 8.1 Summary and analytical discussion on classical hierarchical routing protocols

Sliding window interval determines the optimal CH selection probability in each round of LEACH-SWDN. Optimal clustering leads to load balancing and balanced energy consumption in every round of LEACH-SWDN. LEACH-SWDN needs further improvement to reduce the control packet overhead which may lead to increased network load. Limited scalability of LEACH-SWDN requires an enhancement to make it suitable for large scale network topologies. However, LEACH-SWDN is not suitable for real time applications as it lacks QoS awareness. Mobility is another aspect which needs to be further explored to make it suitable for dynamic network scenarios.

Application specific behavior is one of the key aspect of ALSPR protocol which is achieved by perfect tuning and optimization of complex control attributes. Genetic algorithm and simulated annealing (GA-SA) performs hybrid optimization which enhances the network lifetime depending upon application specific needs. ALSPR protocol utilizes application specific clustering for load balancing and GA-SA optimization to attain balanced energy consumption and enhanced network lifetime. ALSPR protocol needs further enhancements in scalability to make it suitable for large scale network topologies in multi-hop environment. It fails to deal with SNs mobility in dynamic scenarios. QoS awareness of the protocol is another area which is still unexplored. ALSPR protocol is capable of selecting alternate path during primary path failures and ensures fault tolerant operation.

Q-LEACH protocol achieves enhanced network lifetime and stability period by utilizing the concept of randomized clustering for optimized sub sectoring which in turn leads to optimal distribution of SNs. Q-LEACH also provides better network coverage and optimal energy depletion of SNs. However, Q-LEACH needs enhancements to handle mobility in dynamic network scenarios. Limited scalability of protocol is another area of concern. Q-LEACH is not suitable for real time applications as it lacks QoS awareness.

Evolutionary approach applies modified fitness functions (cohesion, separation) in addition to ERP functions to attain optimal dynamic clustering which leads to a better stability period and enhanced lifetime for heterogeneous networks. Optimal clustering in ERP also ensures balanced energy utilization of SNs during its network operation. However, protocol still needs further improvement in its fitness function to prolong stability period as in its current state it fails to achieve stability in certain situations. Limited scalability, inability to handle mobility in dynamic networks requires further enhancement in the protocol. QoS awareness of the protocol is still unexplored.

A cooperative strategy and cooperation attribute builds up a fairness mechanism to achieve a better trade-off between energy consumption and network performance parameters. This leads to balanced network load in C-RPL protocol. It works well for centralized networks. However, further enhancement of protocol is needed for decentralized network scenarios. C-RPL protocol is a better choice for real time applications due to its QoS awareness. It exhibits moderate scalability which needs further improvement. Further enhancements are required to deal with SNs mobility.

OZEEP protocol achieves high energy efficiency by utilizing the concept of genetic fuzzy system and attains optimal CHs. OZEEP exhibits very good level of scalability and hence it is suitable for large scale network topologies. Protocol handles SNs and sink mobility in dynamic network scenarios effectively. It is a good choice for reliability based applications due to its fault tolerant nature and it maintains alternate path during the path failures. OZEEP protocol is also suitable for time driven applications.

MTPCR protocol exhibits high energy efficiency due to optimal path search and path maintenance procedure. It achieves better transmission bandwidth and protocol is able to handle mobility effectively. MTPCR is suitable in large network scenarios for multi-hop environment due to its very good level of scalability. MTPCR is fault tolerant as it handles path breakages effectively due to its multipath nature. MTPCR is a good choice for reliability based applications. High guaranteed bandwidth of MTPCR protocol makes it suitable for time driven applications.

Multicast tree optimization and Distributed Minimum transmission (DMT) leads to balanced and reduced energy consumption in EAODV. EAODV is suitable for real time applications due to its QoS awareness factor which maintains guaranteed bandwidth, lower delay, improved control overhead, less packet loss, higher delivery ratio, and balanced energy operation. EAODV effectively handles mobility of SNs or sink in dynamic network scenarios. However, limited scalability of protocol needs further improvement.

PHASeR utilizes blind forwarding and gradient maintenance measure to achieve better network performance and energy efficiency. Handling mobility in dynamic scenarios and fault tolerance are the main focus in PHASeR protocol. It is able to select alternate path during path failures due to its multipath nature. Protocol needs further enhancements for QoS awareness and to study the effect of channel fading on its performance. PHASeR protocol exhibits a very good level of scalability. It is a better choice for time based applications such as radiation mapping.

Fuzzy and non-fuzzy formulations in HEEDML deal with five levels of energy heterogeneity. HEEDML achieves high energy efficient operation and better network performance by utilizing balanced clustering method and fuzzy/non-fuzzy formulations up to five levels. A further enhancement is required to deal with mobility issue and QoS awareness. HEEDML does not provide fault tolerance and is not able to select alternate path during path failures. HEEDML is more suited for small size networks due to its limited scalability.

An improved FSR (Fish eye State Routing) algorithm and energy abundant path selection method is utilized by EA-FSR protocol for less energy consumption. However, it sacrifices end to end delay and jitter for improved energy consumption. EA-FSR fails to deliver in high mobility based applications and higher control packet overhead is another major issue. Future enhancements of the protocol are required to support real time applications by embedding QoS awareness. EA-FSR fails to select alternate path during path failures. It does not exhibit fault tolerant behavior.

EGRC protocol is best suited for Underwater Acoustic Sensor Network applications where reliability of data transmission is the prime objective along with energy efficiency. EGRC exhibits fault tolerant behavior. It supports data aggregation, location awareness and shows a good level of scalability as well. EGRC supports load balancing through optimal clustering. Duty cycle mechanism and optimal clustering concept in turn leads to energy efficient operation of EGRC protocol.

Data aggregation feature is supported by LEACH-SWDN, ALSPR, ERP, C-RPL, OZEEP, EAODV, PHASeR, HEEDML, EGRC protocols. However, Q-LEACH, MTPCR, EA-FSR protocols do not perform data aggregation. Location awareness is used to enhance the energy efficiency of SNs [55–57]. Q-LEACH, C-RPL, OZEEP, PHASeR, HEED-ML, EA-FSR, EGRC support location awareness. OZEEP, MTPCR, EAODV protocols effectively handle mobility based application due to their query based nature.

### 8.2 Summary and analytical discussion on SI based hierarchical routing protocols

Virtual clustering with mobile sink approach and particle swarm optimization leads to energy efficient behavior of EPMS. EPMS is not suitable for large networks due to its limited scalability. Protocol needs further enhancements to handle mobility of SNs and QoS awareness. EPMS fails to select an alternate path during path failures and doesn't exhibit fault tolerance.

Optimized CH selection is achieved using artificial fish swarm algorithm and a fitness function that selects best set of CHs which leads to reduced energy consumption per round in AFSA protocol. It exhibits a good level of scalability. However, it does not provide QoS. AFSA still needs validation of its behavior and results in NS2. AFSA protocol needs further enhancement for large network scenarios.

A PSO based multi agent model utilizes intelligent software agents to obtain a better QoS measure in QoS-PSO protocol. QoS-PSO is good choice for real time applications. High scalability of protocol makes it suitable for large scale network topologies. Due to its multipath nature it effectively handles path failures and exhibits fault tolerant behavior. However, protocol needs further enhancements to effectively handle high mobility and multi sink architecture.

Load balanced clustering, multi objective fitness function and PSO based encoding leads to reduced energy consumption and enhanced network lifetime of PSO protocol. PSO protocol needs further enhancements to handle mobility in dynamic network scenarios. PSO exhibits good scalability. Protocol lacks QoS awareness and does not provide fault tolerance.

PSO-ECHS attains better network performance and high energy efficiency by applying particle swarm optimization and fitness function. A weight function based clustering procedure provides load balancing. PSO-ECHS exhibits good scalability to handle large network scenarios in multi hop environments. However, future enhancements are required to embed the fault tolerant behavior for reliability based applications.

HSA-PSO protocol attains high energy efficiency, better convergence and high search efficiency by utilizing hybrid harmony search and PSO. However, future enhancements are required to improve scalability of protocol for large scale network scenarios. Mobility and fault tolerant feature of HSA-PSO is still unexplored.

Fuzzy c-mean based balanced clustering, hybrid firefly and simulated annealing based optimization conserves energy in SIF protocol. SIF defines application specific fitness function and exhibits application specific behavior. It extends network lifetime as per nature of application. Protocol needs a significant improvement in terms of scalability to deal with large network scenarios in multi hop environment. Future enhancements are required to build up fault tolerance and effectively handle the mobility of SNs and sink in dynamic network scenarios. EPMS, AFSA and SIF protocols support location awareness.

Optimal clustering during setup phase and bee colony optimization during data transfer phase are the main focus in PECE to attain balanced energy consumption and highly energy efficient operation. PECE exhibits fault tolerance by providing alternate path selection during path failures in the network. Scalability of the protocol still needs an improvement. Future enhancements are required for QoS awareness and mobility aspect.

A new improved encoding of harmony memory, effective local search and a new dynamic adaptive parameter HMCR in IHSBEER results in high energy efficient operation and enhanced network lifetime. It shows better performance for small networks. However, moderate scalability is still a concern as it needs a significant improvement to handle large network scenarios. Protocol also lacks QoS awareness. Future enhancements are required for QoS awareness and fault tolerant behavior.

PDORP utilizes genetic algorithm and BFO optimization along with hybrid properties of PEGASIS, DSR to conserve energy and QoS awareness. PDORP handles real time applications effectively. However, PDORP fails in dynamic environments. It requires further enhancements to handle mobility. Protocol fails to maintain alternate path during path failures and does not exhibit fault tolerance. PDORP is suitable for large network scenarios as it exhibits very good scalability.

Honey bee mating based clustering and light weight trust method provides enhanced network lifetime in LWTC-BMA protocol. LWTC-BMA shows good scalability however it needs further enhancements to handle mobility for dynamic scenarios. QoS awareness and fault tolerance features are still unexplored in LWTC-BMA.

Designing low-power scalable network, energy efficiency, throughput, link quality and scalability are the main focus of ABC-SD. It attains energy efficiency by applying ABC Meta-heuristic and cost function. ABC-SD exhibits QoS awareness and therefore is a good choice for real time applications. It shows a good level of scalability. ABC-SD fails to select an alternate path during path failures. Future enhancements are required to effectively handle SNs and sink mobility for dynamic network scenarios.

Unequal clustering, Fuzzy logic and ACO are the key aspects of FAMACROW protocol which leads to energy efficient operation. FAMACROW exhibits a very good level of scalability for large networks. Future enhancements of protocol are required for mobility aspect, QoS awareness and fault tolerance.

BeeSwarm protocol achieve high energy efficiency using ABC meta-heuristic based optimal clustering. BeeSwarm protocol needs an improvement in terms of scalability. Further enhancements in the protocol are required for its application specific implementation. QoS awareness and fault tolerance are the areas which need to be worked upon.

Bee agent model and agent–agent communication conserves energy in BeeSensor. BeeSensor is a good choice for reliability based applications due to its fault-tolerant behavior and multipath nature. QoS awareness and moderate scalability of BeeSensor is still a concern. The Scalability of Bee Sensor is required to be validated for large scale networks. Future enhancements of protocol are required to handle the mobility of SNs, sink.

AFSA, PSO, PSO-ECHS, HSA-PSO, SIF, PDORP, LWTC-BMA, ABC-SD, FAMACROW, Bee Swarm, Bee Sensor protocols exhibit data aggregation property. However, QoS-PSO, PECE, IHSBEER protocols do not perform data aggregation.

## 9 Conclusion and future directions

In recent past, the WSNs are becoming more popular due to its increased application in remote sensing, health care, earthquake or volcano prediction, environmental monitoring, structural health monitoring, intrusion detection, target tracking, military and surveillance. Energy consumption is a significant problem for these systems due to restricted battery capabilities of SNs. Hardware restrictions necessitate the requirement of energy efficient design and development of hierarchical routing protocols. This article is an effort towards this direction, as it provides a comprehensive review for energy efficient hierarchical routing protocols based on classical and Swarm Intelligence. Article presents an in depth analytical comparison of various classical and SI based hierarchical routing protocols based on various performance metrics which are energy efficiency, data aggregation, QoS, scalability, load balancing, fault tolerance, location awareness, multipath and query based. Classical hierarchical routing emphasizes on optimal clustering, load balancing, evolutionary methodologies to find a better trade-off between energy efficiency and network performance. Swarm Intelligence based hierarchical routing adds a fair contribution by suggesting design, algorithmic level enhancements through biologically inspired meta-heuristic approaches that offer better solution for optimization problems. The review concludes that classical and swarm intelligence based hierarchical routing protocols help in finding better solutions for reduced energy consumption which in turn lead to enhanced network life time. Paper also highlights some open issues and challenges related to this domain for the design and development of energy efficient routing protocols.

It is suggested that future research should concentrate on design and development of application specific routing protocols. Special attention is needed for the development of energy efficient routing protocols for applications which require QoS services like video and imaging, real time applications, surveillance monitoring. Little research has been done so far in this area and it requires to be further explored. Mathematical modeling of routing protocol should be encouraged to explore designed system to a larger extent and give it a broader perspective. It has been observed from the survey that usually protocol assumptions regarding SNs and sink are stationery. However, it is usually not a real world situation. Applications like target tracking, surveillance monitoring pose a requirement of mobility. Further research is required to explore ability of routing protocols to handle sink/SNs mobility, overhead due to dynamic topology, QoS requirement in an energy constraint environment. The experimentation of the algorithm on real test beds should be encouraged because there may be certain aspects of a protocol which may get discovered there and may not get discovered on simulator. The cost factor for experimentation on actual test bed is a point of concern.

It is expected that this will motivate researchers to consider various protocol attributes while designing and developing energy efficient routing protocols which are energy efficiency, application domain, mathematical modeling, QoS measure, simulation/real test bed implementation. Future research will permit and enable the investigator to achieve fair comparisons and setting goals to attain better solutions.

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