A SURVEY OF THE LITERATURE ON WIRELESS SENSOR NETWORK ROUTING TECHNIQUES

Dr.N.Mohana Suganthi ,SUMANTA KUMAR SINGH Department of Computer Science & Engineering Raajdhanni Engineering College

Abstract:

Steering in Wireless Sensor Networks (WSNs) plays a significant job in the field of climate situated checking, traffic observing, and so forth. Here, wide commitments that are made toward directing in WSN are investigated. The paper predominantly expects to arrange the directing issues and analyzes the steering related streamlining issues. For accomplishing the thought process, 50 papers from the standard diaries are gathered and essentially explored in a sequential manner. Afterward, different highlights that are connected with energy, security, speed and unwavering quality issues of steering are talked about. In this manner, the writing is dissected in view of the reproduction climate and exploratory arrangement, mindfulness over the Quality of Service (QoS) and the sending against different applica-tions. Likewise, the advancement of the directing calculations and the meta-heuristic investigation of defeat ing improvement are investigated. Steering is an immense region with various perplexing issues and consequently, different exploration holes alongside future headings are likewise introduced.

KEYWORDS Routing; QoS; Optimization; Meta-heuristic

1. Introduction

Remote Sensor Networks (WSNs) are as of late evolved to help a lot of uses, which incorporate traffic control, home computerization, savvy battlefield, climate checking and some more. WSN consolidates different sensors that are circulated around a specific hub for accomplishing the compu-tational tasks [51,41].

In WSN, steering is a vital undertaking that will be han-dled cautiously. Steering strategy is required for sending the data between the sensor nodes and the base stations, so as to establish communication. The main criterion, which is focused in this paper, is about the routing protocol that varies based on the application. The routing problem leads to decreased net- work lifetime with increased energy consumption. So, various routing protocols have been developed to minimize the energy consumption and to maximize the network lifetime. The rout- ing protocols can be categorized based on the nodes' participa- tion, clustering protocols, mode of functioning and network structure. The various challenges in routing include energy consumption, node deployment, scalability, connectivity, cov- erage, security. [52]. Fig. 1 explains the routing protocol of the wireless sensor networks.

The presented paper collectively reviews the routing analy- sis, which is performed in the wireless sensor networks such as the mobile ad hoc network, to maximize the network lifetime

and to decrease the energy consumption. The review is done using 50 research articles that occupy a supreme position in the leading journals of the past 10 years. The articles are acquired based on the top search results from the online library of the leading journals. The papers that are based on routing and its optimization are mostly selected. Section 2is dealt with the chronological survey of all the papers that are collected. The collected papers are then used to select, catego- rize and describe various features. Section 3gives a detailed analysis of the routing protocols, explaining about various simulators, tools, network configurations, QoS parameters and their applications. Section 4reveals various optimization problems as well as the meta-heuristic procedures that solve them in the cloud environment. Next, Section 5conveys the research gaps and the challenges. Finally, Section 6ends the review with an informativeconclusion.

2. Routingprotocolsforwirelesssensornetworks

Reviewchronology

Fig. 2illustrates the chronology-based percentage calculation forroutinginwirelesssensornetworks.In2015,42%ofworks are done in the field of routing, which is comparatively 4% higher than the works that are done in the consecutive years 2008, 2009, 2011 and 2012. About 8% works are done in 2014 and 2016. The predicted data represent the recent research and developments in the field of routing in wireless sensor networks. The routing protocols have been developed to face the challenges, which are caused due to the features such as energy, security, delay and error. The protocolthat

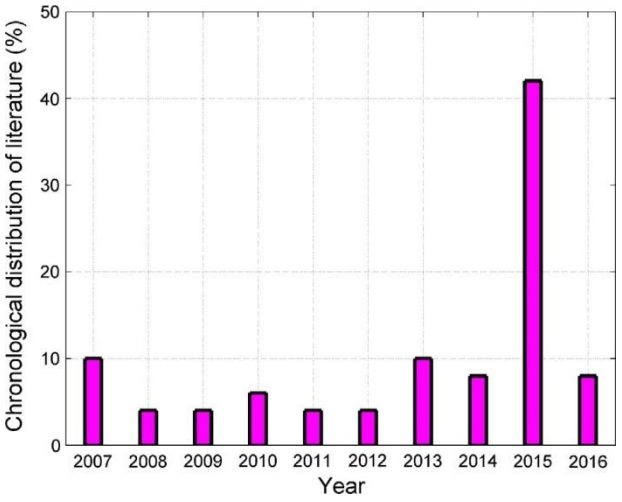

Figure 2 Development of routing protocols for WSN over the time period.

imparts energy efficiency has been developed more in number than the other featured protocols and it has peaked 38.46% in 2015. The percentage of works that pertain to the development of security-based routing protocols has been found to double every year, since 2013. Further, the number of delay-less protocols that has been developed from 2011 onward is found to exhibit a constant percentage of 6.67%, except for the year 2015.Theinterestshowntowarddeveloping areliableprotocol has dropped in 2012. However, the demand for error-free protocolshasrisentoabout50%in2015.

Featured routingprotocols

The routing problems of WSN have been addressed in a large number of works. On reviewing the work, various features such as Energy, security, delay and error that pose challenges are identified. This section gives a discussion on the works, per- taining to those features, in a separate manner.

Energy efficientprotocols

In 2008, Wang et al. [1]have developed a multi-rate routing scheme to optimize routing in Distributed Source coding (DSC). The network performance was enhanced by energy scheduling, which satisfies the end to end transmission rate.In addition, they have also proposed the energy usage schedul- ing concept for efficient energyoptimization.

Phan et al. [2]have worked on the joint cross-layer opti- mization method for efficient routing and energy distribution to meet the QoS requirements. They have found that the opti- mization problem equals the two-step convex problem and the problem of increasing the network lifetime is quasiconvex. In 2007, Baek and Veciana [9]have focussed on the trade-off optimization problem to achieve energy efficiency in ad hoc network systems. The trade-off optimization is done between the improved spatial balance of energy burdens and the energy cost of spreading traffic. Further, multipath routing was found to minimize the probability of energy loss. Guha et al. [11]have examined power-aware routing schemes in wireless net- works to propose a fair coalition routing algorithm. They have found the group sharing properties to vary for individual shar- ing. Lin et al. [28]have proposed routing algorithms for effi-cient energy usage with great competitive ratio, which is asymptotically optimal to the number of nodes. Kim etal. [34]have tried to maximize the wireless sensor networks and proposed the distributed joint routing and medium access con- trol algorithm. The addressed linear programming problem has been evaded with dual composition. In 2009, Yang et al. [14]haveoptimizedtheroutinganddetectioni nafusioncenter for route pre-computation and proposed three routing metrics. The joint optimization technique involves the Neyman- Pearson concept to solve the energy-efficient routing problem. ChamamandPierre[35]haveaddressedtwom ainproblemsin wireless sensor networks, namely increased network lifetime and less energy dissipation. To meet these goals, they have optimally planned the sensors states in cluster-based sensor networks. The problem was viewed as an integer linear pro- gramming model and Tabu search heuristic has reduced the computational time. In 2010, Luo and Hubaux [30]have addressed the problem of longevity of wireless sensor networks and proposed a primal-dual algorithm. They have also dealt with the joint optimization problem of routing and joint sink mobilitytoraisethenetworklifetime.Valentin ietal.[39]have used the dynamic multi- objective routing algorithm to frame the simple hybrid routing protocol. Energy efficiency was assessedtofindthebestroutetothesinknode.

In 2011 Li et al. [22]have studied the dual optimization problem of lifetime and distortion to develop a generalized power consumption model. The dual-level optimization prob- lem was solved using the gradient algorithm. In 2013, Habibi et al. [7]have proposed an optimization method to assess the direct transmission's preference in a given node configuration or in a cooperative transmission. The optimal broadcasting power and the optimal power values for the cooperative trans- mission phase were identified and the whole technique can solve the real-world problems. Shah and Lozano [16]have developed Fixed tree Relaxation-based algorithm and Itera- tive distributed algorithm to solve the power efficient distribu- tion issues. The problem

was assumed as an optimization problem. The Iterative distributed algorithm has offered good trade-off between the energy efficiency and the estimation accuracy. Hamadi and Chen [32]has utilized the trade-off among the timeliness and the energy consumption to manage the redundancy in heterogeneous wireless sensor networks. In the trade-off optimization problem, the best level of redun- dancy in both the path and the source was identified to increase the network lifetime. In 2014, Long et al. [48]have developed a new routing scheme, called tree-based diversion- ary, to raise the network lifetime. Chen et al. [50]have maxi- mized the system utility with energy allocation in routing. They have developed a low complexity online solution andusedadistributedalgorithmtocheckit.In2015,Maddali [20]have proposed the multi-cast routing protocol to maxi- mize the network performance. Alanis et al. [26]have developed an optimal quantum-assisted algorithm, called non-dominated quantum iterative optimization algorithm, for the wireless multi-hop networks. The synergy among the quantum parallelism and hardware has greatly reduced the computational complexity. Zhang et al. [27]have proposed a multi-objective optimization problem, which solves the trade-off between load balancing and energy efficiency. A Nash bargaining framework for green network routing was developed based on the game theoretical model. The model is considered as a threat value game, since the performance of the model threats the value to minimize the cost. Gupta and Bose [31]have developed dual minimum total power strategies to reduce the energy intake in wireless sensor net- works by maximizing the path lifetime and minimum- weighted total power strategy. Luo et al. [37]have saved energy via an opportunistic routing algorithm to increase the networks' lifetime. Tang et al. [38]have developed a cost-aware secure routing algorithm, which involves probabilistic-based random walking and energy balancecon- trol, to solve the network lifetime issue. Ghaderi et al. [40]havesolvedtheminimumenergyroutingprobleminwireless networks by offering solutions to pseudo-polynomial com- plexityanditsrelatede-optimalapproximation.Guptaetal. [45]have applied an energy efficient homogeneous clustering method on the wireless sensor network to maximize the net-worklifetime.Additionally,theDijkstra's shortestpathalgo- rithm was introduced to perform route optimization in the clustered network. Rahat et al. [46]have presented a novel multi-objective routing optimization for the sensor meshnet- works to increase the networks' lifetime. The search space withtheshortestpathpruningandagraphreductionmethod was used to identify the routes clearly. The optimal routes weregotusingtheevolutionaryalgorithm. Hsuetal.[49]have developed an opportunistic-based routing model to solve the energyconsumptionissueintheunderwatersensornetworks.

Delay-lessprotocols

In 2011, Basan and Jaseemuddin [3] have considered both the operations of the underlying directional MAC protocols and the physical interference to develop a

abstraction. The developed model renders a framework toanalyze the wireless link conflicts by evaluating the end-to- end delay transmission. In 2012, Dai et al. [24] have proposed a correlation-aware QoS routing algorithm to send the visual information with quality of service. A correlation-aware internode differential coding scheme was introduced to mini- mize the traffic hub and the average delay in different source codings is studied. In 2013, Chen and Shen [18]have worked on the routing schemes in delay tolerant networks and devel- oped an inter- landmark data routing algorithm, called DTN- FLOW. In 2014, Cheng et al. [41]have developed an efficient QoS-aware geographic opportunistic routing scheme for the wireless sensor networks. In terms of latency, the protocol has organized the prioritized sets. In 2015, Tang et al. [5] have studied the routing algorithm of network-on-chip and intro- duced a novel metric, known as routing pressure, for evaluat- ing the performance of the routing method. The traditional methods use degree of adaptiveness as the metric measure, but it imparts very less performance. So, the new metric mea- sure that has the capacity to predict congestion has been introduced. Jie et al. [15]have addressed the issue in the pub- lishing or the subscriber system and proposed a novel algo- rithm, known as Hierarchy hybrid routing scheme. The proposed scheme was able to deliver the local publication to the core domain and solves the issue in remote publication routing into the edge domain, allowing the objects to be rou- ted aptly to the subscribers. Zhang and Dong [19] have exam- ined few issues in routing such as the delay in transmission and proposed a bypassing void routing protocol. The whole theory was dependent upon the virtual coordinates to prevent the void problem, occurring from the source to the destina- tion. Maddali [20]have developed the multicast routing pro- tocol for maximizing the network performance. For this study, they have considered the parameter-delay to optimize the developed protocol. Hsin et al. [23]have developed the ACO-based Pheromone Diffusion adaptive routing frame- work, which depends on the Network information region framework and combines the spatial and the temporal net- work information. High performance improvement with more importance toward the delay measure was achieved with their work. Chang et al. [25]have modified the ant colony optimization-based adaptive routing and proposed the regio- nal ACO-based cascaded adaptive routing for enhancing the load balancing and performance. The delay distribution of thedevelopedmethodhasalsobeenstudied.Ala nisetal.

[26]have focussed on routing in wireless multi-hopnetworks and proposed an optimal quantum-assisted algorithm, called non-dominated quantum iterative optimization algorithm. The end-to-end delay parameter was considered to optimize. Tang et al. [38]have proposed a cost-aware secure routing algorithmtoincreasenetworklifetimeands ecurity.Theaver- age delay of various security parameters was addressed. Guptaetal.[45]haveemployedclusteringt echniqueandcon- sidered the delay problem in wireless sensor networks to increase the network lifetime. Hsu et al. [49]have addressed the issue of long propagation delay in underwater sensor net- works and developed the opportunistic-based routing. In 2016,Nohetal.[13]haveexaminedthechal lengesinreliable underwater sensor events such as ocean current to develop a HydroCast,ahydraulicpressure-basedanycastroutingproto- col and the average end-to-end delay performance was evaluated.

Secureprotocols

In2012,Liuetal.[29]haveintroducedanovelthreephasedis- joint routing scheme, called the Security and Energy-efficient Disjointroute,tomaintainnetworksecurity .Theoptimization problem was solved by selecting apt routing strategies and hence, information sharing was protected. In 2013, Hamadi and Chen [32]have used trade-off optimization in security and managed redundancy in heterogeneous wireless sensor networks.

In 2014, Saleem et al. [44]have suggested a biologically- inspired self-organized secure autonomous routing that relies on improved ant colony optimization to achieve secure data transformation. Long et al. [48]have addressed the issue of source location privacy and developed a new routingscheme, calledtree-baseddiversionary.Hideandseekstrategyhasgen- erated fake source routes to protect the source location and diversionaryrouteshavepreservedprivacyinthenon-hotspot region. They have also detected a new direction-oriented attack in the wireless sensor networks. In 2015, Frechette et al. [21] have proposed a capped hose model for robust net-workdesigntrafficproblems.Theyhavefoundthatthemulti-hubroutingdesignsareneededforboththehubandtheshort- est path. Tang et al. [38]have proposed a cost-aware secure routingalgorithm,involvingprobabilistic-basedrandomwalk- ing, to solve the security issue. Ghaderi et al. [40]have extended the single-hop physical layer security technique to multi-hop wirelessnetworks.

Reliableprotocols

Despite the reliability of the routing protocol said to be char- acterized based on simply error, the causes of error differ in various aspects. They rely on the reliability of the topology,link between the nodes, protocol flow and many more. Yet, the discrepancy on the aforesaid aspects leads to error in the communicating messages. Some significant protocols that are robust against such errors are reviewed here. In 2007, Lin et al. [28] have used packet delivery rate as the metric measure and proposed a model to detect the efficiency of multi-hop radio networks. In 2010, Wu et al. [33]have worked on the routing schemes of multi-hop wireless networks, mainly con- centrating on the application-oriented quality of service during video transmission, and proposed a novel routing algorithm. They have also investigated the routing flexibility by analyzing the PSNR levels and developed a quality-driven cross-layer optimization scheme to increase the video quality. The reliabil- ity of delivery ratio in wireless sensor networks has also been discussed using a multi-objective algorithm, known asdynamic multi-objective routing algorithm, by Valentini et al. [39]. In 2011, Basan and Jaseemuddin [3] have considered the average packet deliver ratio for studying the performance of the pro- posed underlying directional MAC protocols and the physical interference, in order to develop a color conflict graph abstrac- tion. Li et al. [22]have considered the packet loss probability measure to study the effectiveness of the proposed method in solvingthedualoptimizationproblemoflifetimeaswellasdis- tortion and developed a generalized power consumption model.

In 2012, Liu et al. [29] have introduced a novelthree-phase disjoint routing scheme, called the Security and Energy-efficient Disjoint route, for maintaining the network security and increasing the network lifetime. In addition, thepacket

interception probability was measured during the routing pro- cess. The Bit error rate with their power transmission strategies has been simulated and compared by Habibi et al. [7], in2013, to propose an optimization method that determines the direct transmission's preference with cooperative transmission. Shah and Lozano [16] have used mean square error as the metric for their two algorithms, namely Fixed tree Relaxation-based algorithm and Iterative distributed algorithm analysis. In 2014,Chengetal.[41]haveinvestigatedQo Sroutinginwire- less sensor networks and introduced QoS-aware geographic opportunistic routing scheme. In terms of packet speed ratio, the protocol has organized the prioritized sets. Saleem etal.
[44] have proposed a biologically-inspired self-organized secure autonomous routing for increasing the network lifetime with low energy consumption and used the metric measures such as packet rate and deliveryratio.

In 2015, Tang et al. [5]have studied the routing of WSN and introduced a novel metric, known as routing pressure, for evaluating the performance of the routing method using packet injection rate. Surendran and Prakash [17] have devel- oped a QoS-constrained fault tolerant ant look-ahead routing algorithm for efficient MANET routing. It is important totake the routing decisions for the maximization of network life and the developed model has aided in detecting the correct route and look-ahead route pairs. In this study, the packet delivery ratio was used. Zhang and Dong [19]have solved the issue of routing such as packet delivery ratio and proposed a bypass- ing void routing protocol. Maddali [20]have considered vari- ous parameters such as bandwidth and packet delivery ratiofor optimizing the developed multicast routing protocol. Hsin et al. [23]have utilized packet injection rate, along with other parameters, for studying the performance of the developed ACO-based Pheromone Diffusion adaptive routing frame- work. Chang et al. [25]have used packet injection rate as the metric measure for evaluating the performance of the ACO- based cascaded adaptive routing and to enhance the load bal- ancing as well as the performance. The BER analysis has been performed by Alanis et al. [26]to achieve routing in the wire- less multi-hop networks using the optimal quantum-assisted algorithm, called as the non-dominated quantum iterative optimization algorithm. Gupta and Bose [31]have also used the BER analysis for studying the performance of the devel- oped dual minimum total power strategies, in order to reduce the energy consumption in the wireless sensor networks. Luo et al. [37] have achieved energy saving through the opportunis- tic routing algorithm and compared its performance with the existing route algorithms using the receiving packet ratio.For the developed cost-aware secure routing algorithm, Tang et al. [38]have used delivery ratio and other parameters to solve the issues of network lifetime. Puggelli et al. [43]have developed a tool, which helps in the deployment of wireless sensor networks and promotes rapid prototyping. They have developed a mixed-integer linear program and a polynomial time heuristic to obtain the desired results for the identified issues. They have performed OPNET simulation and used packet injection rate as the metric measure for evaluating the networkmodels.

In 2016, Noh et al. [13] have concentrated on the problems such as ocean current and used the packet delivery ratio as the metric measure to develop a HydroCast, a hydraulic pressure- based anycast routing protocol.

3. Analysis on routingprotocols

Simulation

Simulations are performed in various platforms or software or tools or simulators to analyze the routing protocols in wireless sensor networks. Majority of works are simulated using NS-2 simulator [8,12,14,17,19,28,39–41,44,45], MATLABplatform [11,31,37,43],OPNETsimulator[3,38,43],Noximsimulator [5,23,25], CVX 1.22 simulator [27,6]and IEEE.802.11 tool [8,12,28]. Works have also tested on the following: (i) other platforms such as OPDMAC [3], C++ [14,15], JAVA [24]and Micaz [41,49]; (ii) simulators that include Monte Carlo [14], HHR [15], CVX 1.22 [27,6], OMNET ++ [29,48]and TOSSIM [47]; (iii) tools that include Grin Graph theory soft- ware [1], Link contention graph and maximal clique [2], Set-dest[12],LEDA[14],JM12.2[33]andILOGCPLEX[35] and (iv) standards that include IEEE.802.11.4 [45], NSFNET [15,27], DART and NET [18], IEEE.802.15.4 [36,39], IEEE 802.15.4/zigbee [37]and Tiny OS 2.11 with CTP standard [47]. Table 1 lists the details regarding the various simulations that are performed in earlier works.

Networkconfiguration

The selection of network configuration is highly necessitated, while running the simulation experiments. The 8-level routing topology [1], 2-D mesh topology [5], Abilene and Telstra [21], Regular grid topology [9], 8-ary-2 mesh network topology[23], 16 16 mesh network topology [25], Abilene [27], Global net- work topology [33], Energy optimal topology [35], Random topology [36], Grid topology [39], One source one sink topol- ogy [37], and Telos B notes-hardware [44]are the types of topologies, which have been used in the study of routing in WSN, and they are interpreted in Table 1.

QoSawareness

The quality of service routing plays a significant role in the wireless sensor networks. Various parameters are considered for studying the QoS. Energy efficiency, network lifetime, delay,packetdeliveryratio,overhead[8,17,20,47],bandwidth, packet usage, utility, network throughput, error probability [1,33,22,7,16,18,26,31], data rate [1,14,3,22,24,38,47],hop [41,48,45], transmission cost, controlling cost, differential coding efficiency, link quality and spatial correlation coeffi- cient are those parameters, which are collected from various review papers, and they are shown in Table 3. The relative focus on those parameters by the researchers is illustrated in Fig. 3.

Among the QoS parameters, energy efficiency [9,28,1,2,14,39,22,7,16,48,50,20,21,26,27,31,37,38,40,45–47], networklife-time[1,2,11,30,31,35,37,46,48],packetdeliveryratio[3,5,13,17,19,20,23–25,28,33,37,38,41,43,44], delay[3,5,13,15,18–20,23–26,38,41,45]and throughput [3,8,12,17,20,33,25,49]were given a wide consideration for improving the performance of routing in wireless sensor networks. About 44% of the works were done to increase the

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measure. Maximization of the network lifetime was also given importance that 24% of the works have dealt with it.

Applications

The types of routing protocols are analyzed and their applica- tions are discussed in this section. The applications of the rout- ing protocol can be categorized into three, namely Environment-specific, Task-specific and general. Table 2reveals all these categories. The environment-specific category involves applications such as Underwater sensor network [13,49], Australian telecom network, American backbone net- work [21,27]and Renewable energy sources [28]. The task- specific applications include Distributed video coding [22,24]and Multimedia system [23,25]. Other applications include Beam forming antenna [3], Zigbee [37], Sensor network for office [43], NoC [25], Open field [44], Victoria & Albert Museum Network, London [46], CitySee large scale urban net- work [47], Panda-Hunter Game [48], Video streaming [33], Distributed Source Coding Based Applications [1], Multi-hop network [2,12], Distributed network [6], Hybrid network [8], Information centric network [15], Delay tolerant network of buildings and other landmarks [18], Seismic exploration [19], Core network [20], Heterogeneous network [32] and Dynamic network [36].

4. Optimizing routingprotocols

Problemmodels

The researchers have developed routing algorithms to solve several routing issues. Most of these problems are related to optimization and the problem models are tabulated in Table 4. The optimization approaches are greatly used to solve prob- lems such as joint routing [28], trade-off optimization [9,32,46],costofcommunication[42],cross-layeroptimization [1,2], Energy efficient joint routing and power allocation optimization[28],multi-objectiveroutingoptimization[26,27,39], opportunistic-based routing [49], energy saving and network lifetime problem [43,38], two-level routing optimization [22,6], combinatorial optimization [14], collision probability minimization [36]and Discrete optimization [44]. Of these works, trade-off optimization and multi-objective routingopti- mization problems have been largelysolved.

Table 3 QoS awareness in the current routing protcols.

Authors [Citation]	Network lifetime	Delay	Packet delivery ratio	Energy efficiency	Over Head	Throughput	Error probability	Data rate	Hop count	Other metrics
Baek and Veciana [9]	U			U						
Guha et al. [11]			U	U						
Lin et al. [28]										
Kim et al. [34]	U			U			U	U		
Luo and Pottie [42]	U									
Wang et al. [1]										
Phan et al. [2]	U			U		U				
Yang et al. [14]				U				U		
Chamam and Pierre [35]	U									
Luo and Hubaux [30]	U									
Wu et al. [33]			U				U			
Valentini et al. [39]			U	U						
Basan and Jaseemuddin [3]		U	U			U		U		
Li et al. [22]	U			U			U	U		Spatial correlation coefficient
Dai et al. [24]		U						U		
Liu et al. [29]			U							
Leinonen et al. [6]				U			U			
Habibi et al. [7]				U			U			
Shah and Lozano [16]		U								Bandwidth, success rate
Chen and Shen [18]	U									
Hamadi and Chen [32]		U	U						U	
Cheng et al. [41]										Data transmission cost, control message cost

Saleem et al. [44]			U							
Long et al. [48]	U			U					U	
Chen et al. [50]				U						Utility
Gulyas et al. [4]		U	U							
Tang et al. [5]					U	U				Scalability, congestion avoidance
Shen et al. [8]		U	U		U	U				
Banaei et al. [10]			U							
Jie et al. [15]		U								
Surendran and Prakash [17]										
Zhang and Dong [19]										
Maddali et al. [20]		U	U	U	U	U				
Frechette et al. [21]			U	U						Transmission power cost
Hsin et al. [23]		U	U			U				
Chang et al. [25]		U	U			U				
Alanis et al. [26]		U		U			U			
Zhang et al. [27]				U						
Gupta and Bose [31]	U			U			U			Route transmit power
Luo et al. [37]	U		U	U						
Tang et al. [38]		U	U	U				U		

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Table 3 (*continued*)

Authors [Citation]	Delay	Network lifetime	Packet delivery ratio	Energy efficiency	Overhead	Throughput	Error probability	Data rate	Hop count	Other
Ghaderi et al. [40]			∪							
Puggelli et al. [43]	∪			∪					∪	
Gupta et al. [45]		∪		∪						
Rahat et al. [46]	∪			∪		∪				
Hsu et al. [49]						∪				
Meng et al. [12]	∪		∪							
Noh et al. [13]										Collision
Mansourkiaie and Ahmed [36]					∪			∪		
Gao et al. [47]										

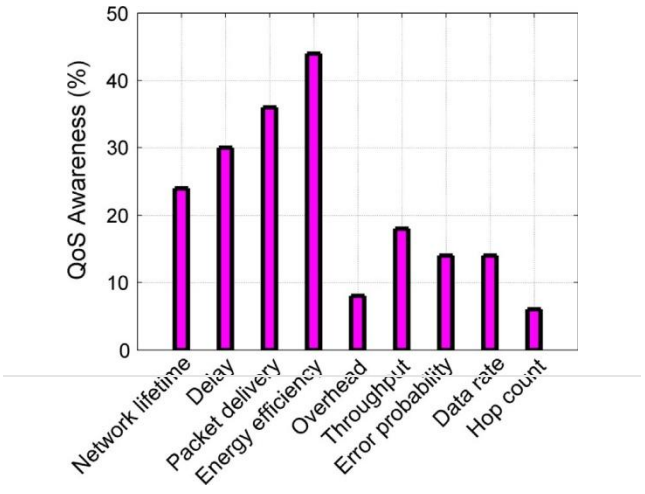

Figure3 Focus on QoSparameters.

Meta-heuristicprocedures

In this section, various procedures that are meta-heuristic or non-meta-heuristic in nature are discussed and tabulated in

Table 5. About 16% of the works, which achieves routing problem optimization, depends on the non-meta-heuristic procedure and only 10% is based on the bio-inspired algorithms. Among the bio-inspired routing protocols, ant colony optimizationtechniqueanditsvariantsarelargelyusedtooptimize the issues in wireless sensornetworks.

5. Research gaps and challenges

Practicalchallenges

1. Diverse topologies: In the hierarchical routing protocol of WSN, it is significant to develop merged and multiple topologies.Particularly,inhierarchical routing,executing and merging the cluster-based topology with the grid-based topology is a great challenge. All topologies have theirownmeritsanddemerits.Enhancingtheperformance with these merits is quite a hardtask.
2. Multiple sources/destinations: Except few routing algo- rithms, most of the routing algorithms enable communication between a single source and destination. The packet collision may result in multiple source as well asdestination networks, due to the contention among the nodes. Hence, for avoiding the packet collision in these types of networks, multiple types of networks must be taken into account. Moreover, multiple sinks often cause information flooding, which the future researchers should substantially reduce along with the controloverhead.
3. Multi-objective routing: The algorithms that are developed for routing should meet many application-specific requirements such as throughput, capacity, coverage, end-to-end delay, real-time delay and collision. Therefore, developing a routing protocol that meets multiple requirements to achieveoptimizationisoneoftheopenchallenges.
4. QoS with multiple constraints: The QoS requirements such as outage probability, delay jitter, end-to-end delay and bandwidth consumption should be considered to achieve aflexibleroutingalgorithm.Outageprobabilityisoneof

the QoS requirements of the cooperative routing algo- rithms. In some wireless networks, meeting a single QoS requirement is itself a great issue.

5. Security routing: Most of the routing algorithms are designed to increase the coverage area and the network per- formance, but the security issues are given less importance. Hence, the means to achieve secure routing, with no loss in the network performance and the coverage area, is extre- mely encouraged by making a node to have its influence on the signals of othernodes.
6. Energy demand: Energy can be obtained by vibration, solar or any other physical criteria. The sensor nodes absorb the environmental energy for establishing an effective commu- nication. In the energy-limited wireless networks, the energy harvesting nodes are used as the relay nodes in cooperative diversity. From the literature survey, it is found that the cooperative routing algorithms that are related to energy harvesting are verylimited.
7. Network applications: Lot of works are done in the area of wireless sensor network applications. But, very few works are concentrated on the applications of other network area and they include the delay-sensitive applications and the bandwidth-limited applications. So, the potential applica- tions of cooperative routing such as LTE networks, cogni- tive radio networks, cellular networks, and wireless LANs can be considered for futurestudy.
8. Development platforms: In this survey paper, it is identified that most of the routing algorithms are estimated through theoretical analysis and simulation. Very few algorithms are related to the practical aspects of routing. So, executing thesekindofapproachespavesawayfor futurework.

Practicalchallenges

The challenges that are addressed in the present routing algo-rithmscanberectifiedbyusingsoftcomputingandcomputa- tional intelligence. The future possibilities can be asfollows.

1. Design and applications: Wireless sensor networks are appliedinmanyareas,whichincludemonitoringofthebio- logical system with tissue-implanted sensors and monitoring forest fire with air-dropped sensors. The sensor nodes have to be in specific position for some applications and some don't need the nodes to be specific. So, it is important to design the type, location and the number of sensor nodes for futureapplications.
2. Sensor localization: Sensor localization refers to the cre- ation of location awareness in all the sensor nodes that are deployed at a specific point. Geometric-aware routing can be used to obtain accurate information. Also, the local- ization methods that utilize the time-of-arrival of the signalsfromthebasestationsareusedinWSNs.
3. Routing based on energy awareness: Maximizing the net- work lifetime in WSN is a major factor, which is to be paid attention. Frequent recharging of the nodes is not possible because of its expense. For some applications, the network life expectancy of several years is needed. Routing involves the retrieval of the path of a message, which is communi- cated from a source node toward a destination node. Among the two types of routing methods, theproactive

routing methods involve table generation and store theroutes without any route matching. But, in the reactive routing methods, the routes are subjected to computation. In addition, the hybrid of both the routing methods isapplied in the densely deployed networks to avoid large memory intake of the routing tables. The memory usagecanbereducedbynetworkclusteri ngtoo.

4. QoS aware routing: QoS can be defined as the measure of the service quality that is concerned with the end-to-end applications/users. The QoS parameters include packetloss, jitter, delay, available bandwidth and fairness. It isvery significant to increase the network utilization with the QoS parameters and in accordance with the application requirements.

6. Concludingremarks

Selecting the best route is more challenging in the field of WSN. The selection depends upon lot of parameters. Hence, various parametric features of the routing protocols have been discussed and analyzed in this paper. Further, the chronologi- cal survey reveals that about 42% of the works are done in 2015,whichiscomparativelyhigh.Therou tingproblemsoccurduring data transmission from the source node to the destina- tion node. The energy efficient problem, which constitutes about 44% of the works, has been discussed more. Trade-off optimization and the multi-objective routing optimizationapproach have been used in various studies. Moreover, themeta-heuristic study depicts that about 16% of the routing problems have been analyzed using the non-meta-heuristic procedures and only 10% have used the bio-inspired algo- rithms. Of all the bio-inspired algorithms, ACO has beenextensively applied to solve the routing issues. The future chal- lenges include security routing, energy demand and multi- objectiverouting.

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