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Review Article
An Extensive Survey on Performance Comparison of Routing Protocols in Wireless Sensor Network

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Abstract

A Wireless Sensor Network (WSN) is a special kind of *ad hoc* network with distributed sensing and processing capability. Routing protocols for wireless sensor networks are responsible for maintaining the routes in the network and have to ensure reliable multi-hop communication. Studies from 2006 until early 2015 distinguished three categories of routing protocols i.e., network structure, routing paradigms and initiator of communication. The routing protocols belonging to the first category further classified as flat, hierarchical and location based routing protocols, the routing paradigms classified as single path and multipath and the initiator of communication classified into source initiator and destination initiator routing protocols. The operations of representative members from each category are described and the comparative analyses of the performance of each routing protocol are presented. A literature has been extensively studied to highlight the properties and limitations of existing routing protocols and future research issues, which helps to improve the routing protocols for another domain.

Key words: Wireless sensor network, routing protocols, network structure, routing paradigm, flat, hierarchical and location based routing protocols, single path routing protocols, multipath routing protocols, source initiator routing protocols, destination initiator routing protocols

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INTRODUCTION

A Wireless Sensor Network (WSN) consists of sensing devices with an inbuilt capability to communicate with other nodes through small transceivers. These sensors are distributed in the sensor field to monitor targeted area. The number of sensor nodes in a network may vary and a large sensor network exists with thousands of nodes in it. Usually some of the nodes in wireless sensor network are used as sensors which may act as a source that generates data. This data reaches to the sink either in a multi-hop fashion or in a single hop fashion if the source is a neighbor of the sink. Each node in a WSN is equipped with a radio transceiver, a small microprocessor, an energy source or a battery and some other electronics components. The cost of sensor nodes varies with specification of resources such as memory size, computational speed and bandwidth. The WSNs may be used in a variety of everyday life activities or services such as environmental monitoring, in-plant robotic control, smart homes, military surveillance, industrial applications, forests, habitat monitoring, farmlands and precision agriculture.

Routing is the main element for WSNs and the primary design goals and challenges for routing protocols are scalability, reliability, lifetime, QoS and energy efficiency. The ways in which routing protocols work make them suitable for certain applications. Routing protocol is responsible for maintaining the routes in the network and have to ensure reliable multi-hop communication. Various routing protocols have been designed and developed for WSNs in order to support efficient data delivery to their destination. Thus, each routing protocol may have specific characteristics depending on the application and network architecture. The main contribution of this study is to provide an exhaustive survey on the routing protocols for WSNs. This study summarized recent routing protocols for WSN to address the issues like energy efficiency, end-to-end delay etc. The objective of routing protocol is not only to improve routing process but also to improve network lifetime, energy efficiency, data delivery, security and reliability etc., at the same time. In Fig. 1, the routing protocols in WSN are classified based on three different categories i.e., network structure, routing paradigms and initiator of communication. The routing protocols belonging to the first category can be further classified as flat routing protocols, hierarchical routing protocols and location based routing protocols. The routing protocols belonging to the second category can be further classified as single path and multipath. The routing protocols belonging to the third category can be further classified as source initiator routing protocol and destination initiator routing protocol.

The proposed survey presents the comparison of different routing protocols for WSNs which helps the readers to choose the efficient routing protocols for wireless sensor network.

There is a large number of current studies, as well as efforts that are on the go, for the development of routing protocols in WSNs. These protocols are developed based on the application needs and the architecture of the network. However, there are factors that should be taken into consideration when developing routing protocols for WSNs. The most important factor is the energy efficiency of the sensors that directly affects the extension of the lifetime of the network. There are several surveys in the literature on routing protocols in WSNs and an attempt is made to present and discuss the existing differences between them and this study.

The researchers make an extensive survey on design issues and techniques for WSNs. They depict the proposed protocols for all the layers of the network stack and the physical constraints of sensor nodes. The possible applications of sensor networks are discussed but the study does not make a classification for such routing[1]. Biradar *et al.*[2], presented the design issues of WSNs and classification of routing protocols. Also, discussed a few routing protocols based on their characteristics and the mechanisms they used in order to extend the network lifetime. However, the proposed survey does not present a direct comparison of the discussed protocols. The challenges in the designing of the energy-efficient Medium Access Control (MAC) protocols for the WSNs was presented by Demirkol *et al.*[3]. Furthermore, it describes few MAC protocols for the WSNs emphasizing their strengths and weaknesses. However, the proposed survey neither discusses the energy-efficient routing protocols developed on WSNs nor provides a detailed comparison of the protocols. Ehsan and Hamdaoui[4], presented few energy-efficient routing techniques for Wireless Multimedia Sensor Networks (WMSNs) and highlight the performance issues of each strategy. They summarized the design challenges of routing protocols for WMSNs followed of the weaknesses of current techniques designed for non-multimedia data transmission. However, it is based on application in WMSNs only.

Pantazis *et al.*[5], categorized energy efficient routing protocols into four main schemes: Network structure, communication model, topology based and reliable routing. The proposed study presented an extensive survey on energy efficient routing protocols for WSNs. The hierarchical routing protocol is more energy-efficient as compared to other routing protocols. Diop *et al.*[6], discussed secure energy-efficient hierarchical routing protocols in WSNs and compare them in terms of efficiency, performance and

security. The industrial wireless sensor networks have attracted more attention due to their large benefits in terms of cost savings, flexibility and faster installation. A number of surveys exist presenting the design principles, the current standards and the challenges in this area several. The researchers presented the analytical review on routing protocols for industrial monitoring applications of the wireless sensor networks technology and according to the industrial requirements they present their comparisons and weaknesses[7].

Due to the importance of routing in WSNs and the availability of a considerable amount of literature in this study, a detailed review becomes necessary and useful at this stage. This study is a dedicated study of routing protocols for wireless sensor network and presents the comparisons of existing routing protocols in terms of performances matrices i.e., security, congestion control, energy efficiency, reliability, scalability, low latency, fault tolerance, data delivery, end-to-end, delay, stability, lifetime and end-to-end throughput. The proposed study help the readers in designing an algorithm for routing purpose or to pick the most suitable energy efficient routing protocol for their network.

TAXONOMY OF ROUTING PROTOCOLS

The growing interest in WSN and the revelation of new architectural technique is the reason for studying of routing protocols. Routing protocols for wired networks and *ad hoc* networks are not suitable to wireless sensor networks. It should be energy conserving, scalable, robust, fault tolerant and self-organizing. Routing is the main element for WSNs and the primary design goals and challenges for routing protocols are scalability, reliability, lifetime, QoS, low latency, fault tolerance, data delivery, end-to-end delay and energy efficiency. The main goal behind the routing protocol design is to keep the sensors operating for as long as possible, so that the lifetime of wireless sensor network can be increased. The ways in which routing protocols work make them feasible for certain applications. Routing protocol has to monitor the change of network's topological structure, locate the destination node, exchange the routing information, choose the route and transfer the information through route. In order to select the most suitable routing protocol for a sensor application, all routing protocols according to a well-defined classified. Using this classification, all protocols become comparable for an application developer. It should be noted that some of these protocols may fall below one or more of routing protocols categories.

Figure 1 shows the classification routing protocols in WSN based on three different categories i.e., network structure, routing paradigms and initiator of communication.

Based on network structure: Network structure or network architecture is used to depict the technique of how data on a network is organized and viewed. It ascribes to the plan of the network, consisting of the hardware, software,

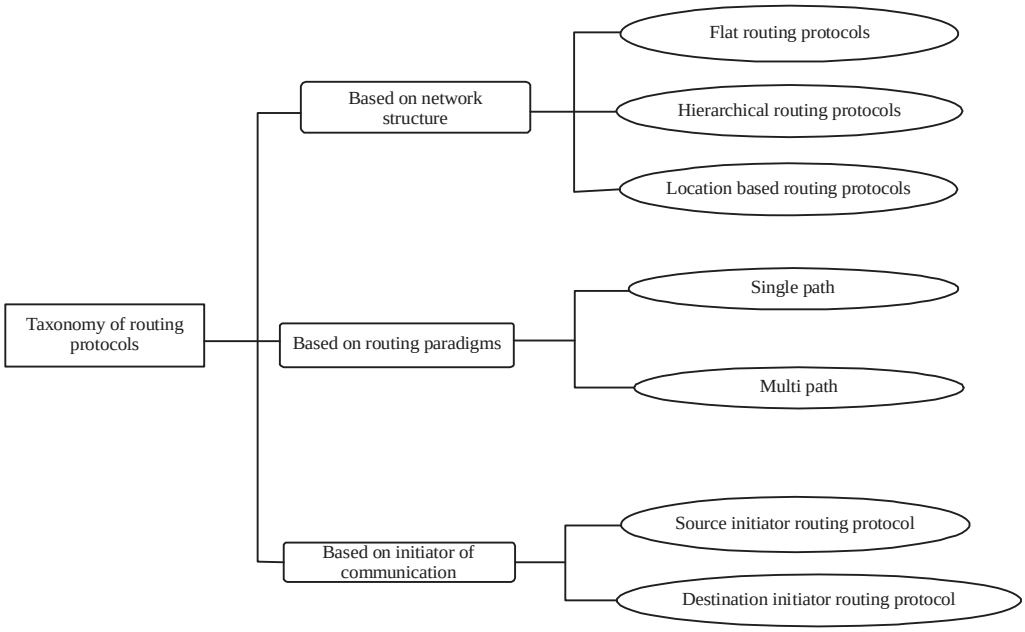

Fig. 1: Taxonomy of routing protocols in wireless sensor network

connectivity, communication protocols and mode of transmission. The structure of the network is very critical for the required performance. This section classify the routing protocols based on the network structure of wireless sensor network which is further divided into three subcategories according to their functionalities. These subcategories are[6] flat based routing protocols, hierarchical based routing protocols and location based routing protocols.

Flat based routing protocols: Flat routing protocols consist of homogenous nodes where all nodes in the network are treated equally. Sensor nodes may find a route consisting of several hops, when it needs to send data to the sink. Flat based routing is needed when the large amount of sensor nodes are required in which all nodes acts same role. Because of a large number of sensor nodes the particular identification (Id) of each and every sensor node is not possible. This leads to data centric routing protocols.

Data-centric routing is different from topology-based and geographic routing in the manner that data is not forwarded to a specific receiver, which is determined by a network address or a geographic location. In data-centric routing, the base station emit's a request for or interest in sensor data and the respective sensors will respond this query. As an example, the sink may request to be alerted, if a sensor measures patient blood pressure increase from 120. This request is disseminated throughout the network and responds by sensor nodes once the event occurs. When the sensor nodes send their data to the base station, mediatory sensor nodes can perform some form of aggregation on the data and send the aggregated data toward the sink. The aggregation process can result in energy savings because to send the data from the sources to the sink required less transmission. The efficiency of data-centric routing protocols depends on the type of requests used for querying sensor data. This section, presents some of the data-centric routing protocols for wireless sensor network.

The researchers proposed an energy efficient routing protocol, named (energy-efficient depth-based routing protocol) EEDBR for UWSNs. The simulation shows that EEDBR contributes to the performance improvements in terms of the network lifetime, energy consumption and end-to-end delay[8].

Hierarchical routing protocols: Hierarchical routing protocols are energy-efficient communication protocols to take for heterogeneous networks where some of the nodes are more powerful than the other ones. The hierarchy of nodes does not always depend on the power. In hierarchical (Clustering) protocols different nodes are grouped to form clumps and data from nodes belonging to a single clump can be combined (aggregated). Coordinating the data transmission activities of all sensors in a clump is the responsibility of high energy node called cluster head. The clustering protocols have several advantages like scalability, provides inherent optimization capabilities at the cluster heads, energy-efficient in finding routes and easy to manage.

Due to limited energy of sensor nodes, it is important to use energy-efficient routing protocol in WSNs. To reduce the energy consumption the cluster-based routing is an efficient, which decrease the number of transmitting messages to the sink node. The LEACH is one of the most popular energy hierarchical routing protocols, which provides an adaptive cluster generation and a cluster head rotation. It assumes a direct communication between sensor nodes and a sink node which limits the communication range. To overcome this problem, the researchers proposed an energy-efficient cluster-based routing protocol, which adopts a centralized clustering approach to select cluster heads by generating a representative path. They proposed a multi-hop routing protocol that allows both intra and inter-cluster communications to support reliable data communication. To prolong the network lifetime the sensor nodes are uniformly distributed in clusters based on a message success rate and a representative path. Simulations show that the proposed energy-efficient routing protocol outperforms the existing protocols up to 2 times, in terms of the distribution of cluster members, the energy consumption and the reliability of a sensor network[9].

Other examples of hierarchical routing protocols are:

- Energy-efficient cluster based routing protocol for wireless sensor networks (VM-LEACH)[10]
- Energy-efficient inter cluster coordination protocol has been proposed EEICCP[11]
- Equalized Cluster Head Election Routing Protocol (ECHERP)[12]
- Heterogeneity aware Hierarchical Stable Election Protocol (HSEP)[13]

Location based routing protocols: In this kind of network architecture, sensor nodes are deployed randomly in an area of interest and located mostly by means of GPS. They are mostly known by the geographic position where they are deployed. These coordinates are calculated by exchanging information between neighboring nodes. Signal strength received from the sensor nodes is used to calculate the distance between those nodes, so that energy consumption can be estimated, thus enabling the best routing to be

selected, reducing energy consumption and optimizing the whole network. The researchers proposed a heuristic neighbor selection mechanism in WSNs that uses the geographic routing mechanism combined with the QoS requirements to provide multi-objective QoS routing (MQoSR) protocol for different application requirements. The QoS routing problem is formulated as a link and path-based metrics. The link-based metrics are divided in terms of reliability, distance to sink, energy and delay and the path-based metrics are partitioned in terms of end-to-end delay, network lifetime and reliability of data transmission. The MQoSR protocol outperforms the other routing protocols in terms of reliable data transmission, time data delivery and routing overhead[14]. Another example of location based routing protocol is location-aware and fault tolerant clustering protocol for mobile WSN (LFCP-MWSN)[15].

Based on routing paradigms: The routing paradigm shows the pattern of routing protocol in which source node sends packets to destination node. Based on routing paradigm the routing protocols are further classified in single path and multipath routing.

Single-path routing: In single path routing, each source sensor sends its data to the sink via the shortest path. Defending against compromised nodes' dropping of legitimate reports and investigates the misbehavior of a maliciously packet-dropping node in sensor networks. Lee and Choi[16] presented a resilient packet-forwarding scheme using Neighbor Watch System (NWS). The routing protocol is specifically designed for hop-by-hop reliable delivery in face of malicious nodes that drop relaying packets, as well as faulty nodes that fail to relay packets. The researchers employ single path data forwarding, which consumes less power than multipath schemes. However, the scheme converts into multipath data forwarding at the location where NWS detects relaying nodes misbehavior. Results show that the proposed scheme achieves a high success ratio in face of a large number of packet-dropping nodes and depending on the number of packet-dropping nodes en-route to the base station it effectively adjusts its forwarding style.

Multipath routing: In multipath routing, each source sensor finds the first k shortest paths to the sink and divides its load evenly among these paths. For the quality of service, the existing multipath routing protocols in WSN have exhibited the effectiveness of traffic distribution over multipath. To provide efficient and failure-tolerant routing scheme, it is desirable to design a reliable and service-driven routing protocol with the consideration of reliability, congestion control and security for multipath. An evaluation metric, path vacant ratio is proposed to evaluate and then find a set of link-disjoint paths from all available paths. To adjust the load over multipath a congestion control and load-balancing algorithm is proposed. A threshold sharing algorithm is applied to split the packets into multiple segments and depending on the path vacant ratio the segments will be delivered via multipath to the destination. Simulation shows the performance of the adaptive and secure load-balance routing scheme in terms of reliability, congestion control, security and fault tolerance[17].

Based on initiator of communication routing protocol: This study classify the routing protocols based on the initiator of the communication. The initiator describes what initiates the data reporting process i.e., source or sink. When any part of a network i.e., the source node or the sink (destination, base station) node needs assistance from another part, it will initiate the routing with another party to transmit and/or receive the data packets or control. Time-driven and event-driven are source initiator routing protocols while query-driven are sink initiator routing protocols. Most routing protocols belong to multiple categories.

Source initiator of communication routing protocol: In a source initiator of communication routing protocols, the routing process is launched by the source node. When source nodes sense any new data it will send to the base station. Source initiated routing protocols use either event driven or time driven data reporting model.

Time-driven: In a time-driven routing protocol, a sensor node is activated in specific moments, when it should carry out its measurement task and forwards the measurement to its next-hop neighbor. These activations can be periodic or one-shot in time. Short periods of activation may cause more traffic in the network and the quality of routing in terms of energy efficiency becomes critical. Time-driven sensors may be scheduled with explicit queries or may be pre-programmed. A time-driven routing protocol can support the reporting of aggregated data or non-aggregated data, complex or simple data and replicated or unique data.

Aliouat and Harous[18], presented WB-TEEN and WBM-TEEN: Two hierarchical routing protocols. These routing protocols adopt time-driven model and use distributed

clustering. The LEACH consumes considerable amount of transmission energy due to a single hop transmission via the cluster-heads (CH). Also, unequal number of nodes occur in different cluster in TEEN making a problem. To solve the problem, the WB-TEEN distributes an equal number of nodes in each cluster and calculates degree. It selects or rejects the membership of the node on the basis of this degree. The WBM-TEEN is an improvement of WB-TEEN which emphasizes multi-hop intra cluster transmission of data to the sink. Simulation shows the performance in terms of energy consumption with respect to the number of rounds, network lifetime of system and number of nodes alive per round.

Event-driven: A sensor node sends its data towards the base station only if a required event occurs (e.g., temperature falls below a given threshold). An event-driven routing protocol can support the reporting of complex or simple, aggregated or non-aggregated and replicated or unique data.

The existing multipath routing protocols for wireless sensor networks demonstrate the efficacy of traffic distribution over multiple paths to fulfill the Quality of Service (QoS) requirements of different applications. However, the performance of these protocols is highly affected by the characteristics of the wireless channel and may be even inferior to the performance of single-path approaches. Specifically, when multiple adjacent paths are being used concurrently, the broadcast nature of wireless channels results in inter-path interference which significantly degrades end-to-end throughput. In this study, a low-interference energy-efficient multipath routing protocol (LIEMRO) to improve the QoS requirements of event-driven applications proposed. In addition, in order to optimize resource utilization over the established paths, LIEMRO employs a quality-based load balancing algorithm to regulate the amount of traffic injected into the paths. The performance gain of LIEMRO compared to the ETX-based single-path routing protocol is 85, 80 and 25% in terms of the data delivery ratio, end-to-end throughput and network lifetime, respectively. Furthermore, the end-to-end latency is improved more than 60%[19]. Based on observations on event-driven wireless sensor networks, an algorithms add information in packets and use negative-ACK packets instead of ACK packets to reduce bandwidth consumption[20].

Destination initiator of communication routing protocol: In destination initiator of communication routing protocol the nodes only send its sense data in response to a request for data. The requests are usually flooded through the network and consume most of the energy sources of nodes. Destination initiated routing protocols use query driven data reporting.

Query-driven: In query-driven data reporting, the base station disseminates its query in the network, while the sensor nodes try to solve this query and send a response back to the base station. The task of a query-driven routing protocol is to route the queries to the measurement area and to route back the response to this query. A query-driven routing protocol can support the reporting of complex or simple, aggregated or non-aggregated and replicated or unique data.

The WSNs require robust wireless communication that is energy-efficient and provide low latency. Various routing schemes have been presented in order to improve the lifetime of these wireless sensor networks and to overcome the energy constraint of sensor nodes. One of the effective schemes is based on clustering of sensor nodes and as well as to improve the network lifetime, decreases the communication latency and to reduce the energy consumption of whole wireless sensor networks as much as possible. This study include a brief survey of the state-of-the-art of various existing clusters based routing algorithms for sensor networks and present a new clustering algorithm named HCBQRP: Hierarchical cluster based query-driven routing protocol for wireless sensor networks. The main goal of this routing protocol is to evenly distribute the energy load among the entire sensor nodes in the network so that there are no overly utilized sensor nodes that will run out of energy before the others[21].

COMPARATIVE ANALYSIS OF ROUTING PROTOCOLS

The classification and comparisons of existing routing protocols in terms of performances matrices i.e., security, congestion control, energy efficiency, reliability, scalability, low latency, fault tolerance, data delivery, end-to-end delay, stability, lifetime and end-to-end throughput presented in Table 1. The routing protocols lie under different categories as mentioned, where the EEDBR is best for improving the energy efficiency in Underwater Wireless Sensor Networks (UWSNs), VM-LEACH gives us best performance in terms of energy and can be used for larger geographical region WSN. From the study it shows that EEICCP and ECHERP outperforms in terms of energy consumption as compared to HCR, LEACH, PEGASIS and BCDCP. The HSEP always prolongs the stability period and network lifetime as compared to DEEC, SEP, ESEP and LEACH. The MQoSR highly outperforms the MCMP in terms of energy consumption, data delivery, average end-to-end delay and

Table 1: Classification and comparison of routing protocols in WSN

Routing protocol	Classification	Security	Congestion control	Energy efficiency	Reliability	Scalability	Low latency	Fault tolerance	Data delivery	End-to-end delay	Stability	Lifetime	End-to-end throughput
EEDBR[8]	Flat	No	No	Yes	No	No	No	No	Yes	Yes	No	Yes	No
EECBR-RP[9]	Hierarchical	No	No	Yes	Yes	No	No	No	Yes	No	No	Yes	No
VM-LEACH[10]	Hierarchical	Yes	No	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes
EEICCP[11]	Hierarchical	No	No	Yes	Yes	No	No	No	No	No	Yes	Yes	No
ECHERP[12]	Hierarchical	No	No	Yes	No	No	No	No	Yes	No	No	No	No
HSEP[13]	Hierarchical	No	No	Yes	No	No	No	No	No	No	Yes	Yes	No
MQoSR[14]	Location	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes
LECPMWSN[15]	Location	No	No	Yes	Yes	No	No	Yes	No	No	No	No	No
RPFS-MP[16]	Single path	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes
ASLBRP[17]	multipath	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	No
WB-TEEN and WBM-TEEN[18]	Time-driven hierarchical	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No
LIEMRO[19]	Event-driven multipath	No	No	Yes	No	No	No	No	Yes	No	No	Yes	No
EERP-ED[20]	Event-driven multipath	No	No	Yes	Yes	No	Yes	No	No	Yes	No	Yes	Yes
HCPQRP[21]	Query-driven hierarchical	No	No	Yes	No	No	Yes	No	No	No	No	No	No

routing overhead. The LFCP-MWSN location-aware and fault tolerant clustering protocol for mobile WSN (LFCP-MWSN) which has less energy consumptions and slightly less end-to-end delay than the existing LEACH-mobile and LEACH-mobile-enhanced protocols. The RPFS-MP is appropriate for the network which suspect malicious nodes that drop relaying packets, as well as faulty nodes that fail to relay packets. The ASLBRP is well fitted scheme for the applications where the performance matrices scalability, reliability, congestion control and security are considered. In battery powered sensors network for balanced energy consumption and network lifetime prolongation the WB-TEEN and WBM-TEEN are well suited. The LIEMRO and EERP-ED is well suited for the applications where quality of data is considered. The HCBQRP is better for balanced energy consumption and robust wireless communication. The EECBR-RP outperforms LEACH and MR-LEACH, in terms of energy efficiency and network reliability.

CONCLUSION AND FUTURE RECOMMENDATIONS

The WSN has opened new large applications in our daily life and many research issues emerged that need different solutions. Current routing protocols are classified according to the existing study direction and the performance issues of each routing protocol are highlighted. It has been realized from the literature study that the routing protocols for wireless sensor network have different methodologies and goals which satisfies the transmission requirements. The main goals from our analysis are the energy efficiency, prolongs the stability period and network lifetime, efficient data delivery, average end-to-end delay and routing overhead as well as defend from faulty nodes. The performance matrices scalability, reliability, congestion control and security are also considered. The study can be extended for mobile wireless networks especially for metrics related to QoS and time constraints.

SIGNIFICANCE STATEMENT

This study presents the taxonomy of routing protocols for wireless sensor networks. Studies from 2006 until early 2015 distinguished three categories of routing protocols i.e., network structure, routing paradigms and initiator of communication. The operations of representative members from each category are described and the comparative analyses of the performance of each routing protocol are presented. A literature has been extensively studied to

highlight the properties and limitations of existing routing protocols and future research issues, which helps to improve the routing protocols for another domain.

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