Investigating and Evaluating Energy-efficient Routing Protocols in Wireless Sensor Networks

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Abstract—**Wireless sensor networks are comprised of a group of nodes, which are randomly distributed in an environment. Since the energy consumptions of nodes are limited in these networks, data should be collected and sent optimally and in an energy-efficient way. The available routing protocols are used to send data in this way. The main responsibility of these protocols is to reduce energy consumption and increase network lifetime in routing. Energy-efficient routing protocols are investigated for such networks in this paper. These protocols are divided into three groups, based on data, network structure and reliability. Regarding data-centric protocols, on-demand and negotiation-based protocols are discussed. Based on the network structure, hierarchical and location-based protocols are introduced. In the reliability-based group, the quality of service and multipath routing protocols are presented. In addition to investigating the protocols of each group and challenges in energy-efficient routing, the obtained parameters are compared in order to introduce the best protocol in each group.**

Keywords—*Energy-efficient, Routing, Protocol, Challenge, Sensor Networks, Scalability, Mobility*

1. Introduction

Sensor networks are comprised of a group of nodes which are distributed in an environment. The nodes are placed either regularly or randomly in the environment. Such networks do not usually have a specific structure, and the nodes cooperate to collect and send data to a base station. Sensor networks are widely used in different areas such as business, industry, military environments, fire alarms, tracing moving targets and traffic surveillance. These networks have some limitations such as energy level, limited radio range, low processing power and low storage memory [1].

In sensor networks, data are collected in the sensing radius of each node in the environment. Then the nodes cooperate to send data towards the sink node. Sensor network routing is completely different from wired network routing. Due to the constraints on energy in sensor networks, it is necessary to use an energy-efficient routing protocol. In other words, energy consumption requires close attention while sending data from a source node to a destination node. That is why, the network lifetime can be increased [1, 2, 3].

The rest of this paper is organized as follows: Parts 2, 3 and 4 introduce and discuss protocols based on network structure, reliability and data, respectively. In Part 5, the final conclusion and future suggestions are presented.

Figure 1 indicates the classification used for energy-efficient routing protocols in this paper.

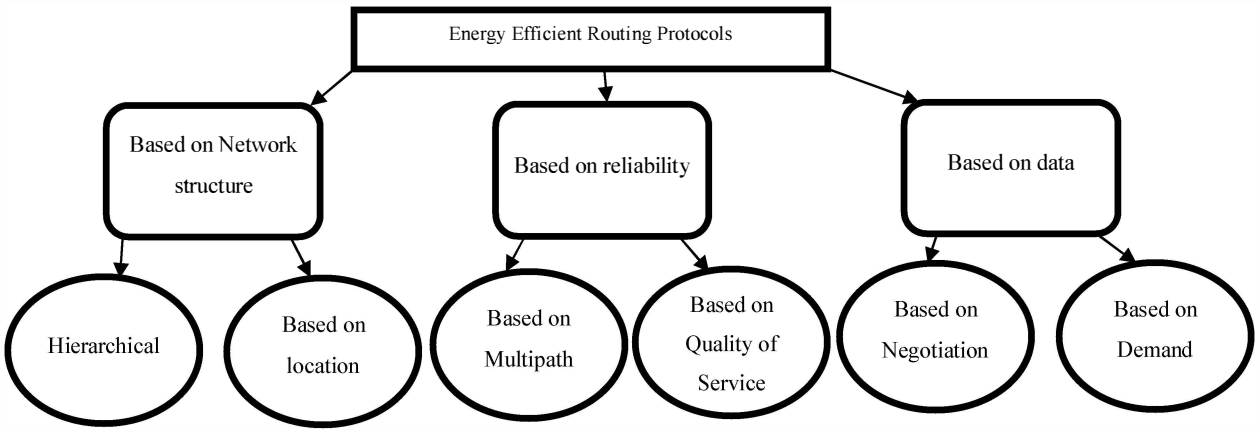

Figure 1: Classification of Energy-Efficient Routing Protocols

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2. Introducing Energy-efficient Routing Protocols in Wireless Sensor Networks

In this part, energy-efficient routing protocols are introduced in sensor networks. First, hierarchical protocols are introduced and a number of selected protocols are investigated. Then location-based energy-aware protocols, multipath protocols, reliability-based and data-centric protocols are introduced. A number of selected protocols are studied to determine the appropriate one.

2.1. Protocols Based on Network Structure

Some protocols are related to the network structure. In such protocols, nodes send their information with respect to the network structure. Based on the uniformity of the nodes, these protocols are divided into hierarchical and location-based groups.

2.1.1. Hierarchical Routing Protocols

In these protocols, nodes have a cluster-like structure. Each cluster has a number of nodes in it. Each cluster has a cluster head, which is usually more responsible for aggregating, compressing and processing the received data and sending them to the base station. If there are many nodes in the network, these protocols can have low energy consumption and higher scalability. The cluster head node only knows about its own group or cluster, which can reduce data overhead in the network. The difference of this group of protocols in cluster-selecting algorithm is in the way data are sent from member nodes to the cluster head and the way data are sent from the cluster head to the base station.

Table 1: Parameters of Hierarchical Routing Protocols

Row	Protocol	Flexibility	Data Aggregation	Power	Scalability	Mobility
1	EEICCP[4]-2013	High	Yes	High	No	Yes
2	ECHERP[5]-2013	High	Yes	High	No	Yes
7	DHAC[6]-2010	High	Yes	Low	No	Yes
8	KMR[7]-2014	High	Yes	High	Yes	Yes
9	Q-LEACH[8]-2013	High	Yes	High	Yes	Yes
10	EE-LEACH[9]-2015	High	Yes	High	Yes	Yes

According to the parameters in Table 1, KMR protocol is thought to be the best choice based on the challenges of wireless sensor networks such as mobility, scalability, the increase in network lifetime and overhead. The main advantage of this protocol is that it prevents the distribution of traffic load among a limited number of nodes. The cluster head is selected with respect to its energy and distance to the central cluster. This algorithm calculates the average energy of nodes first. The nodes whose current levels of energy are higher than the average energy can have the chance to become the cluster head. Compared to Q-LEACH and other protocols, it can be effective in reducing energy consumption. In this protocol, the data, sent to the created clusters, are first broken. Then they are sent. This mechanism can reduce energy consumption. On the other hand, the nodes, which are closer to the central cluster, can be placed in one cluster. This shortens the communication gap between nodes. Therefore, the delay is reduced while sending data, and less energy is required to send data. In this protocol, nodes send their data to the cluster head node in multiple hops. This method can considerably decrease energy consumption.

Unlike KMR protocol, the cluster head is selected merely based on the residual energy of nodes in EE-LEACH protocol. The clusters are created with respect to the distance between each node and its neighboring nodes. After receiving information packets from nodes, the cluster head compresses and sends them to the base station. These two above-mentioned protocols are appropriate in terms of energy consumption; however, KMR can be more effective in increasing the network lifetime due to considering more criteria for the selection of the cluster head node.

EEICCP can be used as an energy-efficient protocol in wireless sensor networks. In this protocol, the head cluster can employ a coordinator to send data to the base station. If the number of cluster heads increases, the traffic load will become heavier on the coordinator node. As a result, energy consumption soars in this node, and data will be interfered. Therefore, this protocol presents a poor scalability. It can be used as an energy-aware routing protocol if there is a small number of a node in the network.

In ECHERP, the multi-hop technique is used to send data from the available nodes in the cluster to the cluster head; then, they are sent to the base station through a specific path. This protocol employs the available energy in the nodes for data routing. One of the problems of this protocol is high overheads in data packets. In fact, one of the responsibilities of this protocol is to predict the amount of energy which each node will have in the future. This can result in heavy data overheads in packets. If the data overhead increases, the energy consumption soars, too. If the number of nodes goes up, the traffic becomes heavier, and the sizes of sent data will increase, then more energy will be consumed. In DHAC protocol, data are sent from the available nodes in the cluster to the cluster head in a multi-hop way. They are sent to the base station in the same way, too. If the number of nodes increases in each cluster, the efficiency of this protocol decreases because there is a limited number of a cluster head node.

2.1.2. Protocols Based on Location

These protocols have location finders. Each node is aware of its location and neighboring nodes. This can reduce the size of routing tables. Therefore, the capacities of sensor nodes can be used more efficiently. The locational information of nodes is used to calculate the distance between the nodes and to estimate the energy required to send data. Since nodes cannot use a universal address in sensor networks, the locational information of nodes can be useful in sending data. If such information is available, a great load of information is decreased, a fact which can reduce energy consumption in nodes. The most primitive location-based protocols have been introduced in case networks. However, since some of these protocols did not consider the energy levels of nodes, they were not much appropriate for sensor nodes. There are some problems in these networks such as long gaps between nodes, sending traffic to further locations and breaking the balance in geographical distribution. Table 3 compares a number of location-based protocols with respect to different parameters.

Table 2: Location-Based Routing Protocols

Row	Protocol	Flexibility	Data Aggregation	Power	Scalability	Mobility
1	LPEDAP[10]-2014	High	Yes	High	No	Yes
2	HGR[11]-2009	Low	No	High	No	No
4	MERR[12]-2008	Low	No	High	No	No
5	OGF[13]-2007	High	No	High	No	No
6	PAGER-M[14]-2007	High	No	High	Yes	Yes
7	TER[15]-2013	High	No	High	Yes	Yes

According to the parameters in Table 2, TER protocol can be thought of as the best protocol among the others in this category. This protocol presents good mobility and scalability. On the other hand, three criteria are considered for energy-efficient routing, such as the available energy in neighboring nodes, the distances between nodes and the distances between neighboring nodes and the base station. Therefore, this protocol can present a better efficiency in the desired network in comparison with other energy-efficient routing protocols. Comparing the physical address of each packet and checking the validity of this address, this protocol can prevent accepting every received packet and provide the security of the sensor network. Although this protocol is complex to some extent, it can result in energy-efficient routing effectively.

LPEDAP is a location-based protocol having a hierarchical structure. In this protocol, the nodes placed at the lower level of tree are collected to do the compressions. Then they are sent to higher-level nodes, which are parents. The parents nodes send the compressed data to higher-level nodes and finally to the base station. One of the problems of this protocol is the increased processing power on lower-level nodes. Therefore, it is possible that the energy levels of lower-level nodes are decreased and finished after a while. If the number of nodes are increased, the energy consumption will increase in lower-level nodes.

HGR is one of the energy-aware routing protocols, which uses the shortest path and a number of nodes on the path to send data to the destination node. Since, in this protocol, each node sends its routing tables alternatively to the neighboring nodes through the shortest path, it cannot be much appropriate for dynamic networks and the movement of nodes will increase energy consumption.

Due to preventing from resending data by nodes and maintaining their energy in MERR protocol, each node sends the collected data through the path, which has a stronger signal. Therefore, the reliability of receiving data will increase. One of the problems of this protocol is its low scalability. Since data are sent through a straight line, it is probable that the energy level of nodes will drop down on that line after a while, and the network lifetime will be shortened.

The performances of OGF and PAGER-M protocols are similar to TER. However, TER considers more criteria in energy-aware routing to reduce energy consumption, which leads to higher efficiency.

2.2. Protocols Based on Reliability

In this group of protocols, the purpose is to increase reliability in delivering packets to the destination node besides reducing energy consumption. Reliability can be guaranteed in many ways, such as the multipath technique, in which several paths are discovered between the source and destination nodes, and then packets are sent to the destination through paths. The packets can be divided into different pieces, which are copied through several paths to increase reliability. This method can be effective in reducing energy consumption. In other words, packets are sent through different paths. Therefore, an appropriate distribution of energy load can be created on the paths to reduce energy consumption and finally increase the network lifetime. The packets can also be prioritized and put in different queues. High-priority packets can be sent through paths with higher bandwidths or lower delays, and less important packets can be sent through paths with lower quality. This method can be very appropriate for real-time traffics. During sending such traffics, the end-to-end delay can also be decreased in necessary packets in addition to reducing energy consumption.

Table 3: Reliable and Energy Efficient Routing Protocols

Row	Protocol	Flexibility	Data Aggregation	Power	Scalability	Mobility
1	EQSR[16]-2010	High	No	High	Yes	No
2	DEERT[17]-2013	High	No	High	Yes	No
3	EENDMRP[18]-2012	High	No	Low	Yes	No
4	MGR[19]-2011	High	No	Low	Yes	Yes
5	I-LQER[20]-2011	Low	No	Low	No	Yes
6	QRPD[21]-2012	High	No	High	Yes	Yes
7	RPL[22]-2011	High	No	High	Yes	Yes
8	MR2[23]-2012	Low	No	High	No	No
9	EECA[23]-2012	Low	No	High	No	No
10	LIEMRO[23]-2012	High	No	High	No	Yes
11	BMRP[24]-2013	High	No	High	Yes	No

According to Table 3, EQSR can be introduced as the best energy-efficient protocol in this group. This protocol uses several parameters such as the ratio of signal power to channel noise, the buffer size of nodes and their energy levels to find several paths. This protocol can repair bad paths locally and recover the path information. Since several paths are used to send pieces of packets, it is not possible to resend a packet and increase reliability. This can reduce energy consumption to an acceptable level. Other capabilities of this protocol are the classification and distinction of different traffics. The packets of multimedia and real-time traffics are sent through paths having higher energy levels and lower noise levels. Normal data traffics are sent through low-priority paths. The distribution of traffic load in this protocol is another factor in the reduction of energy consumption. This protocol should first collect complete information pertaining to the available paths up to the destination node in order to send data. Then, based on the information related to the entire network, the packets are

sent through different paths by prioritizing and with respect to traffic types.

DEERT is another energy-aware multipath routing protocol, which uses the criteria including the energy levels of neighboring nodes and the distance to the destination node, in order to select the best path. Compared to EQSR, DEERT is less powerful. It only considers the two above-mentioned criteria and does not take into account the parameters of quality of service. Therefore, the paths are not prioritized and different traffics can be sent through different paths.

EENDMRP is one of the energy-aware routing protocols, which uses multipath routing. This protocol selects the best path based on the number of hops and the energy level of nodes. Different information pertaining to the paths are stored in each node; a fact which increases the speed of determining the packet routes. Since a great load of information regarding paths and nodes are stored in this algorithm, data overheads are increased. Therefore, more energy is consumed in comparison with other protocols.

MGR is one of the multipath routing protocols, which focuses on the end-to-end delay. Therefore, a path with the shortest delay is selected. In fact, this protocol can be appropriate for real-time traffics, such as audio and video streaming. In addition to meeting the needs for real-time traffics, EQSR can consider the energy levels of nodes and other parameters, while MGR protocol considers only the shortest path to the destination so as to decrease energy consumption.

Like MGR, I-LQER is an energy-aware multipath routing protocol, the main aim of which is to meet the quality of service for real-time traffics. In this protocol, only the path with higher quality is important to transfer real-time traffics.

QRPD is similar to MGR. It selects the desired path only based on the end-to-end delay to send packets.

RPL is a multipath routing protocol with a tree-like structure. The desired paths are specified through parent nodes. In this protocol, the best path is the shortest one to send packets. The main objective of this protocol is to use fewer nodes on the path to transfer data. This can reduce energy consumption to an acceptable extent.

MR2 is a multipath routing protocol that considers the suitable paths with respect to the bandwidth of each path in order to send packets. Like the above-mentioned protocols, this one is appropriate for real-time traffics as well. When nodes direct the packets towards the destination, they can switch to hibernate mode to reduce the energy consumption in the network. Hence, the network lifetime is increased.

EECA directs data towards the destination based on the locational information and the best path. This protocol generates a torrent of traffics to detect paths and acquire complete information about them. Therefore, all the nodes receive the traffics and unicast the response to the source node. This method can have a high data overhead resulting in increasing energy consumption compared to other protocols.

LIEMRO is a multipath routing protocol, which selects the appropriate path based on three criteria, which are the delay, the energy level of nodes and quality of path. Since this protocol needs to detect the path and acquire its information, it produces high overheads so that it cannot be perfectly scalable.

BMRP uses several paths to send data. This protocol does not consider the types of traffics and any priorities for the sent traffics. Therefore, it cannot be appropriate for real-time traffics, which require higher bandwidths and lower delays. It transfers data based on the shortest path and does not have anything to do with the bandwidth and information pertaining to the quality of the path.

2.3. Protocols Based on Data

In this group of protocols, a node can broadcast its data in the network. If other nodes need the data, they send a request to that node to receive it. In this case, they are negotiating nodes broadcasting data throughout the network, or if a node is added to the network, it is broadcast as a request in the network by receiving the necessary updates from neighboring nodes. Nodes can broadcast these requests to both acquire different information regarding other nodes and obtain control information on the activity of other nodes for updates.

Table 4: Data-Centric Routing Protocols

Row	Protocol	Flexibility	Data Aggregation	Power	Scalability	Mobility
1	SPIN-PP[25]-2012	High	No	High	Yes	Yes
2	SPIN-EC[25]-2012	High	No	High	Yes	Yes
3	DRUG[26]-2014	High	No	High	Yes	Yes
6	ERP[27]-2014	High	Yes	High	Yes	Yes
7	DD[28]-2011	High	No	Low	No	No
8	EQR[29]-2011	High	Yes	High	Yes	Yes

According to Table 4, ERP can be known as the best data-centric routing protocol. It is characterized by high mobility and scalability. It also results in the lowest overhead in the network. In other words, it reduces the number of sent packets to the nodes to decrease the overhead. For instance, each node sends its energy level to the neighboring nodes in packets at specific times. In ERP, this action is prevented to some extent to reduce the network overhead. In this case, each node announces its energy level to the neighboring nodes only when it is lower than a specific amount. Therefore, the number of sent packets is decreased. This protocol uses different parameters such as the energy level of each node and the shortest path to decrease the delay in sending packets and the energy distributed among nodes in a combined way to reduce energy consumption. Therefore, this protocol can resolve challenges and problems in routing sensor networks such as mobility, scalability, increasing network lifetime and network overhead.

SPIN-PP can be an instance of data-centric on-demand routing protocols. If a node needs a specific data, it sends a request to the desired node and receives the data. One of the main problems of this protocol is that it does not consider the energy levels of nodes and sends the request of the source node to the neighboring nodes, which are away as far as a hop.

SPIN-EC is actually the improved version of SPIN-PP. Unlike SPIN-PP, SPIN-EC considers the energy levels of nodes. In this protocol, when the energy levels of nodes are

decreased, the numbers of sent messages are also reduced. Doing so, the network lifetime is increased. Having appropriate flexibility and scalability, SPIN-EC and SPIN-PP are used as reference protocols in on-demand and data-centric routings.

DRUG is one of the appropriate protocols in on-demand routing. Compared to SPIN protocols, it provides higher power and lower energy consumption. In this protocol, the focus is to prevent sending extra data as much as possible, in order to increase the network lifetime. According to this protocol, each node uses three messages, which are ADV, DATA and ACK, to communicate with other nodes or to ask for help, if necessary. In DRUG algorithm, only one node is responsible for negotiation in the network, and other nodes are involved in this process less than usual. Therefore, the network lifetime is increased.

Based on the data required by nodes, DD algorithm selects the best path in terms of energy level so that data move through this path towards the destination node. In this algorithm, a referendum is held among other nodes in the network to acquire information pertaining to the entire path. Although this protocol is not highly scalable and mobile, it can operate as an on-demand energy-aware routing protocol.

EQR is another on-demand data-centric routing protocol. Based on the distance to the base station and the energy level of each node, this protocol selects the best route. Unlike ERP, which sends data to the neighboring nodes with a referendum, EQR sends data randomly to one of the neighboring nodes with high energy level. The advantage of ERP over this protocol is data aggregation by which the size of sent data is decreased. Therefore, the energy level required to send data is considerably decreased and the network lifetime is increased.

3. Analysis and Discussion

There are many challenges such as mobility, scalability, network lifetime and overhead in energy-efficient routing in wireless sensor networks. Given these challenges, location-based TER, hierarchical KMR, data-centric ERP and reliability-based EQSR were selected for instance. Among the protocols investigated with respect to different parameters and features, ERP can be introduced as the best protocol. Using the fuzzy method, it performs energy-efficient routing task and provides scalability and mobility for nodes. ERP results in the lowest overhead compared to the other protocols. It can also increase the network lifetime. Due to using more parameters, TER has relatively higher complexity. Its algorithm is also more difficult to understand. Therefore, decreasing the number of parameters in this protocol would reduce the complexity. EQSR is a complete protocol in multicast routing. However, it results in high overheads due to too much control information. Reducing this overhead would decrease the size of sent data and cut down the energy consumption. KMR is a proper protocol in WSN. However, it has high overhead in order to calculate the level of energy of nodes.

Conclusion

In addition to many applications of wireless sensor networks, it is essential to transfer data correctly with respect to energy consumption and network lifetime as well as limited resources of such networks. The most important problem in such networks is routing and sending data to the destination node in compliance with the energy problem. Therefore, energy-efficient routing protocols have important and effective roles in wireless sensor networks. They are divided into three major groups based on data, network structure and reliability. In this study, energy-efficient routing protocols were investigated in wireless sensor networks. Then the necessary classifications were introduced and relevant parameters of corresponding protocols were compared to each other.

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