An Energy-Efficient Ring Search Routing Protocol Using Energy Parameters in Path Selection

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Abstract. Routing protocol is very important in Ad hoc network. From the EERS [3] protocol, we have improved AODV protocol to consume energy more efficiently. However, this method depends only on hop count number, but not energy. This leads to central nodes' exhaustion of energy and influences the entire network lifetime. In this paper, we propose two new protocols from EERS, called Avoid Bad Route (ABR) and Routing Dual Criterion (RDC). In both protocols, we base on energy criteria. Therefore, the lifetime as well as the throughput of the whole network are improved.

Keywords: Ad hoc, Sensor, Routing, AODV, ERS, EERS, RDC, ABR.

1 Introduction

Mobile Ad hoc Networks (MANETs) have become popular in the last couple of years. Routing protocols have been proposed for MANETs. Surprisingly, only a few studies have been made on routing protocols that consider energy consumption. Energy consumption is a major issue when the number of connections between nodes on MANETs increases. Nodes on MANETs and sensor networks are often equipped with small energy sources. The developments of applications on MANETs need to address the energy consumption issues.

There are not many works in the literature addressing the energy consumption in MANETs. In [1] authors proposed a cross layer solution in which route request (RREQ) messages are broadcast at the minimum power required to maintain network connectivity. The proposal leads to longer end-to-end paths but less distance per hop. Doshi et al [2] proposed an on-demand minimum energy routing protocol for ad hoc networks in which they modified the dynamic source routing (DSR) protocol to be an energy based routing protocol. In this protocol, a source node learns many possible

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routes and selects the minimum energy route. The energy cost used is the energy required for transmission of a data-packet over the link.

There are drawbacks with [1] and [2]. First, they assume that the amplifier has the power transmission control capability that depends on the distance to the receiver. In practice, many amplifiers have a fixed power transmission and the hardware for adjusting the power transmission based on distance is very complicated. Also, unequal power transmissions result in unidirectional links which disconnect the network since the route discovery process cannot operate properly. Furthermore, the transmission power levels presented in [2] are small (from I mW to I00mW) compared with the power consumption in electronic circuits and amplifiers. Therefore, the transmission powers cannot become link cost metrics to make routing decisions since we need to consider the total power consumption of these devices.

In this paper, we will modify and add energy information to control packets. This modification will change the routing paths on the network. The purpose is to balance the energy consumption across nodes and to maximize the network life time.

The article is divided into 6 parts. Part I introduces Ad hoc network and proposed algorithm. The second discusses EERS algorithm in general. The third presents the proposed algorithm ABR. Part 4 presents the proposed algorithm RDC. After that, simulation results are presented. Finally, conclusion and future works are discussed.

2 Overview of AODV, ERS and EERS Algorithms

In our previous research, AODV-EERS (Efficient Expanding Ring Search) was presented to improve the shortcomings of AODV and ERS. Besides, the other parameters like hop count, throughput are also optimized more compared to ERS [3],[7],[8].

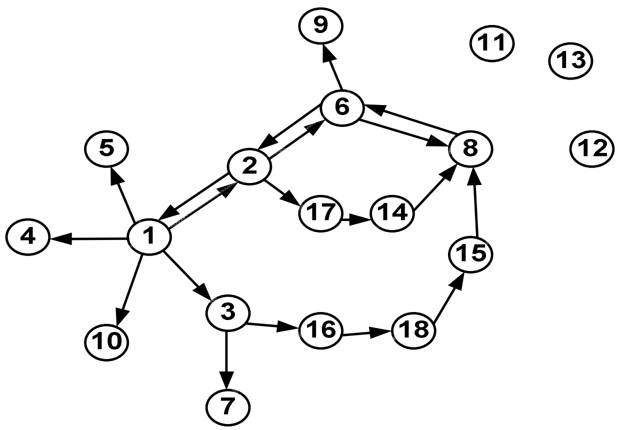

Fig. 1. AODV Routing protocol

Because in our proposal, AODV is a basic protocol that maintains connections on a network, it is helpful to summarize the AODV protocol. AODV is a reactive protocol. In reactive protocols, a route is created at the request of a source node when the node needs a route to a particular destination. In the AODV protocol, a source initiates a route discovery by flooding a Route Request (RREQ) packet when it needs to transmit data to a destination. Every node receiving the RREQ stores the route to the Originator of the RREQ before it forwards the RREQ to other nodes. The destination node or an intermediate node with recent information about the path replies by unicasting a Route Reply (RREP) along the reverse path to the Originator. As the RREP travels back to the Originator, any node receiving the RREP will add or update its route to the destination generating the RREP.

In Figure 1, when Node 1 wants to find path to Node 8, it will broadcast control message to all over the network. In this example, Node 8 replies with information about the path. As can be seen from the figure, Node 15 also participate in the selection process, thus a large amount of energy is consumed.

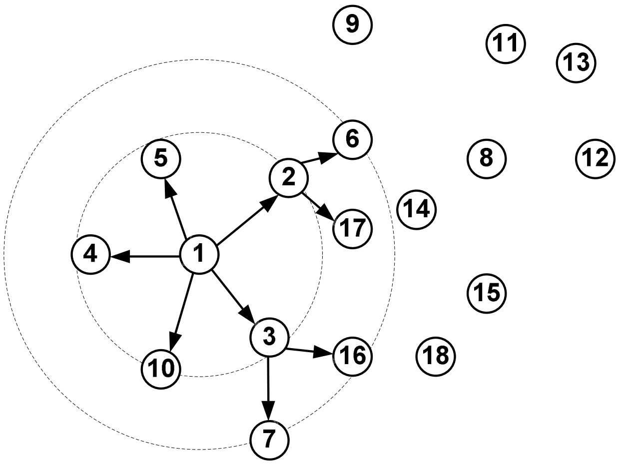

Fig. 2. ERS Routing protocol

To save energy, ERS protocol was suggested [3],[8]. Instead of broadcasting the message all over the network, the protocol expands searching ring with gradually until a path is selected. As can be seen in Figure 2, when Node 1 wants to find path to Node 8, it broadcasts the first message at the radius of one hop. At this time, the message only reaches Node 2, 3, 4, 5 and 10. If these nodes have information about Node 8, they will response, and the path searching process ends. If not any node has information, Node 1 will continue to broadcast the second message at the radius of 2 hops. This time the message will reach node 2, 3, 4, 5 and 10 which process and then forward it to nearby nodes, which are Node 6,7,16 and 17. These nodes receive and process the message. If they have information, they will reply to Node 1, and the process finishes. If not, Node 1 continues to increase the radius more. In the worst case, after several times of expanding ring without finding any path, ERS will come back to work as AODV, which is broadcasting message to the whole network. However, in general, previous researches show that energy is consumed more efficiently in most of the cases.

As can be seen in ERS algorithm, it is unnecessary for Nodes 4,5,7,9,10,11,12 and 13 to forward the message in expanding ring. Therefore, in the previous research [3], we proposed EERS protocol to set up an idle state, not forward message, of these nodes in the next expanding ring in order to save network's energy.

In EERS protocol, we assign one more variable to define whether a node state is forwarding or idle. In idle state, the node will not participate in routing in the following expanded rings any more. This can be explained as the following:

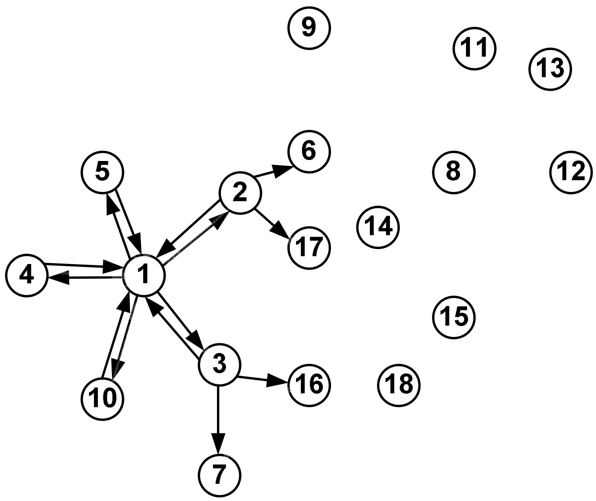

Fig. 3. EERS – operation 1

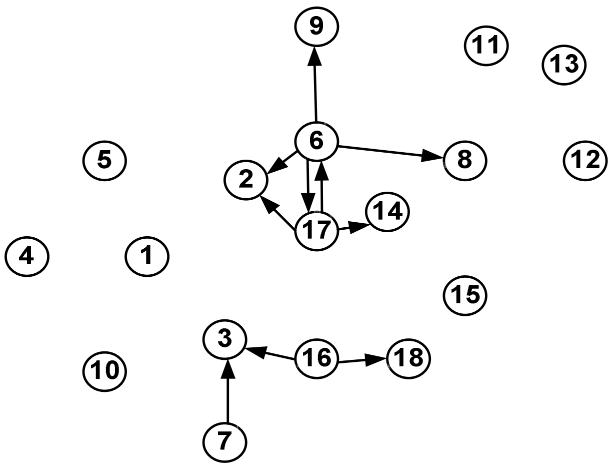

Fig. 4. EERS – operation 2

Initially, all nodes are forwarding. Node 1 broadcasts control searching message to Node 8. Node 1 sends this message to surrounding nodes, which are Node 2,3,4,5 and 10. After that, these nodes will forward it to their nearby nodes: Node 1, 6, 7, 16 and 17. This is shown in Figure 3. In nature, forwarded message is in broadcast form so node 1 will receive response message from its nearby nodes. This is shown in Figure 3. For Nodes 2, 3, after forwarding message, their nearly nodes forward message and then receive their own message. Consequently, it remains in forwarding state. This is shown in Figure 4. The case is different for Node 4, 5 and 10. After forwarding message, without any node behind, they cannot receive any reply that is forwarded reversely. Thus, their state is in idle. They do not participate in the next expanding ring process. Repeatedly, after several times of expanding rings, Nodes 4, 5, 10, 7, 9, 11, 12, 13 will be in idle state because not any nearby nodes are behind. They are not involved in searching process any more. As the results, this process saves quite a large amount of energy in searching path. The details of EERS algorithm has already been specified in the paper [3].

3 Avoid Bad Route (ABR) Protocol

In Ad hoc network, node's energy will decrease over time due to sending and receiving message. The energy loss depends on the amount of data in the network. Obviously, nodes used more often will lose more energy than others. These nodes are often center nodes.

The remaining energy in each node at the same time is different. This makes nodes which have low energy will be run out of energy soon and decrease the network's life time. A load balancing process based on energy will reduce the work load on low energy node and increase network's life time. To implement this we add energy parameters in EERS's routing process.

We propose Avoid Bad Route (ABR) routing protocol which is an expansion of EERS routing protocol. It uses hop count and energy parameters in the route selection process. In ABR protocol, Route Request (RREQ) message will be added *rq_min_energy* field and Route Reply message will be added *rp_energy* field. The *rq_min_energy* field will store energy of the node which has the lowest energy on the path. The *rp_energy* field will store energy of the selected route and it will be added to routing table at source node.

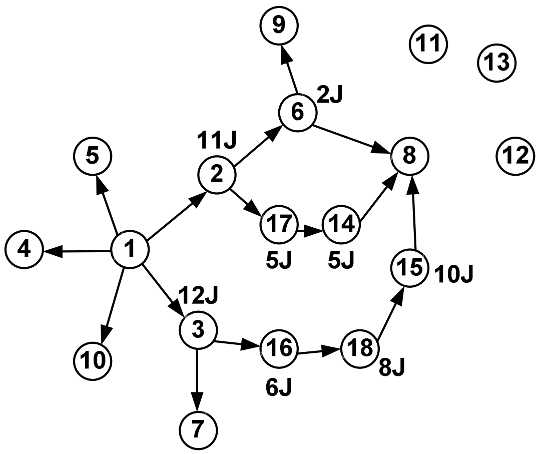

Fig. 5. ABR example

For example in Figure 5, we need to find route from Node 1 to Node 8. In the Figure, when Node 1 sends RREQ, Node 8 will receive three RREQ messages from three different routes that have different hop count number. In the old protocol, node 8 will reply three RREP messages and node 1 will choose the route which has the lowest hop count number. In this case, the chosen route will be 1-2-6-8. But in this route, Node 6 has lower energy. It has energy value of 2J. If this route is chosen, after few times, Node 6 will lose all energy and it will affect to network's life time, throughput and network stability. In ABR, we add energy threshold at Node 8 to ensure the chosen route will meet the energy standard and the node which has lower energy will be avoided. In this example, if we choose energy threshold is 3J, we have two routes that satisfy the energy condition: 1-2-17-14-8 and 1-3-16-18-15-8. In the two routes, we will choose the route which has lower hop count number. And the result is 1-2-17-14-8. If there are not any routes that satisfy the energy threshold, the energy threshold level will decrease. In Figure 5, if we set threshold at Node 8 equal 10J, the above three routes will not satisfy the energy condition. Route 1-2-6-8 has min energy value of 2J. Route 1-2-17-14-8 has min energy value of 5J. Route 1-3-16-18-15-8 has min energy value 6J. All of routes' min energy value is less than 10J. So energy threshold will decrease and its value is the different of max (2J, 5J, 6J) and 3J (3J is the estimated energy based on idle, sending and receiving energy of node in time between source that sends RREQ). So the new energy threshold is 3J. After Node 1 does not receive RREP message from Node 8 for sometimes, it sends RREQ message again. Node 8 receives the second RREQ message. At that time, the energy threshold of node 8 is 3J, so route 1-2-17-14-8 will be chosen because it has higher energy value than the energy threshold and the lowest hop count number. The detail algorithm will be described below:

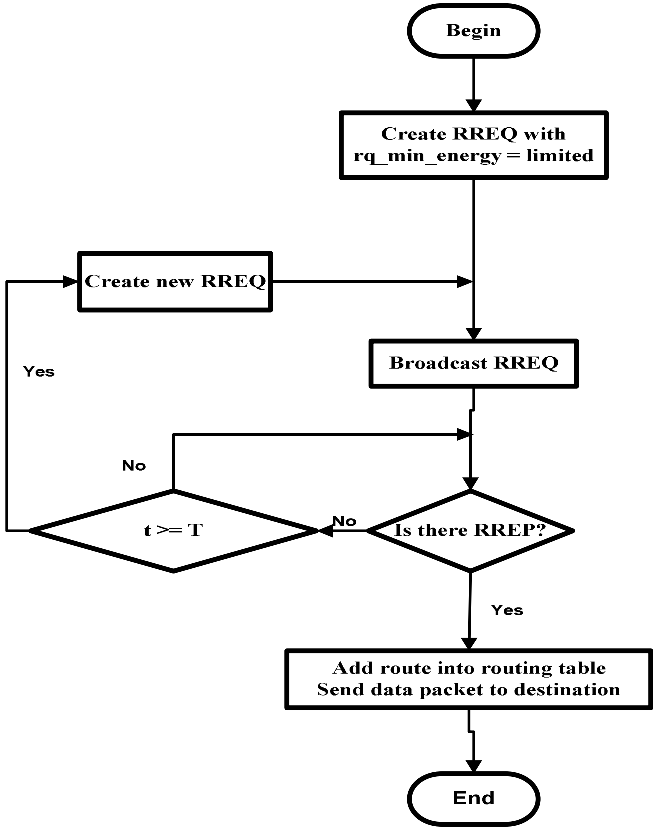

Fig. 6. Source node operation algorithm

Figure 6 describes the operation of source nodes. When a source node wants to find route to the destination, it will send Route Request message (RREQ) with *rq_min_energy* field added. Initially, this field is infinite. Next, the RREQ message is sent to all source's neighbors. The source node starts timer value T (time out value). If the real time reaches to T value and the source node still does not receive any RREP messages, it will resend RREQ message. This process repeats until it finds out the route to the destination.

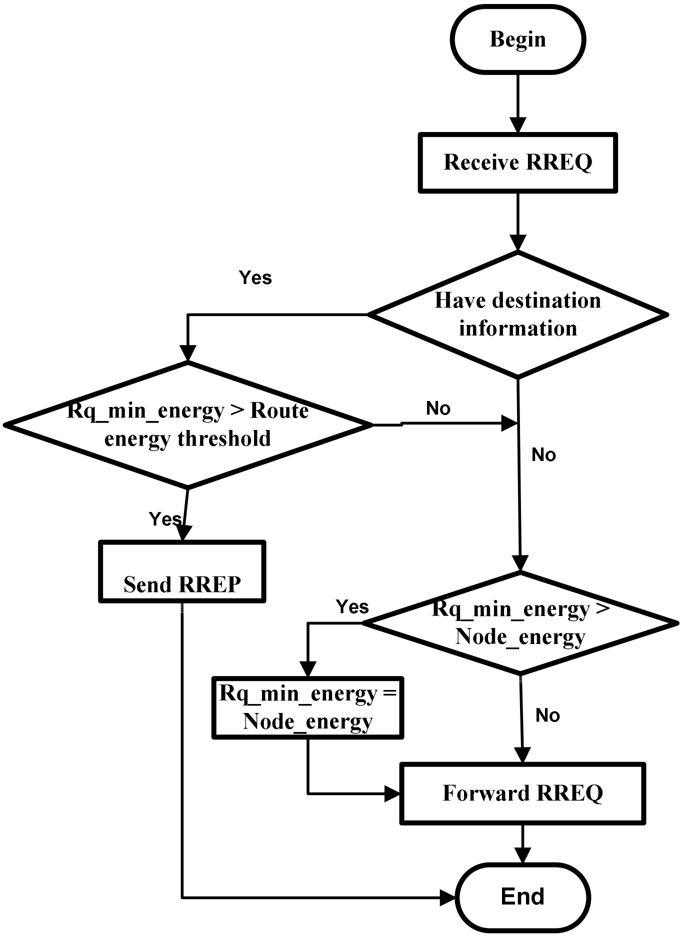

Fig. 7. Intermediate node operation algorithm

Figure 7 describes the operation of intermediate nodes. When a intermediate node receives RREQ message, it will check its routing table to find out information of the destination. If it has the information of the destination, it will compare *rq_min_energy* value in RREQ message with its energy value. If the *rq_min_energy* value is lower than its energy value, it will forward RREQ message to the next node. Otherwise, it will assign *rq_min_energy* value with its energy value. If this intermediate node has the information of the destination and *rq_min_energy* value is higher than route's threshold value from routing table, the intermediate node sends RREP message to the source node. The routing process finishes. And if the intermediate node has information of the destination node but does not satisfy the energy condition, it will be considered as no information about the destination.

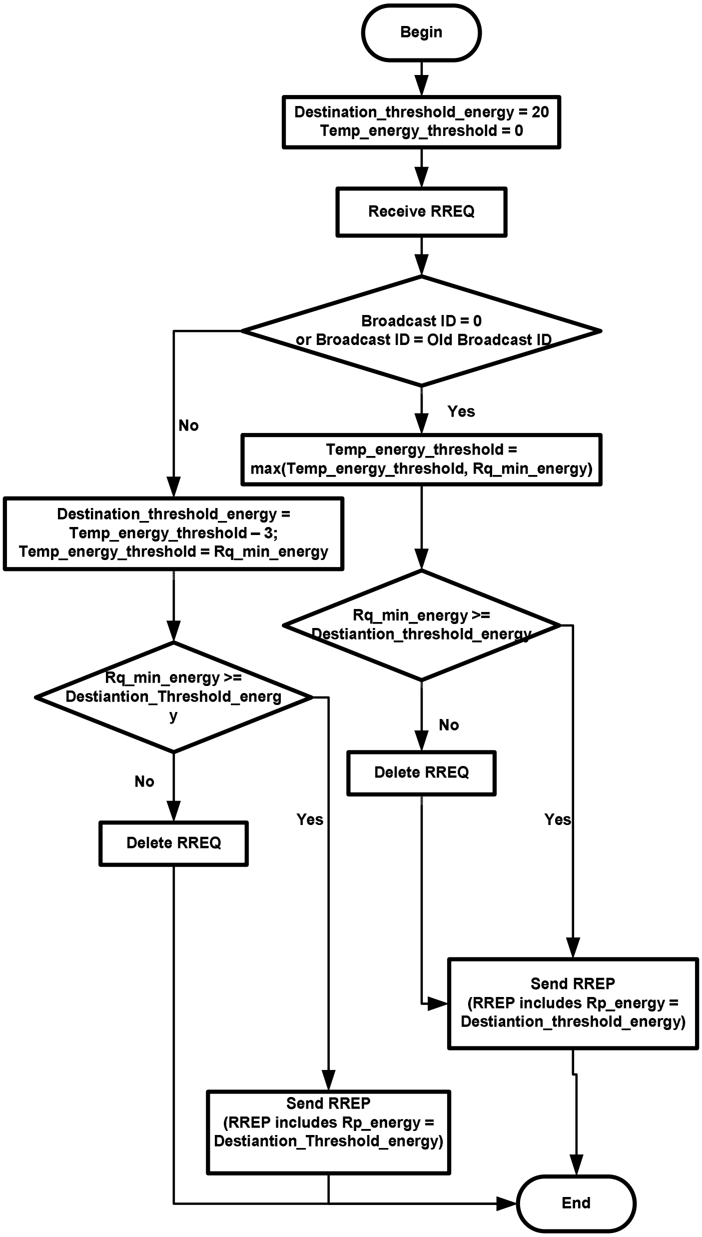

Fig. 8. Destination node operation algorithm

Figure 8 describes the operation of destination node. The destination node has the energy threshold value to determine which route will satisfy. This value is in *destination_threshold_energy* variance. In this example, it is set to 20J. This value depends on network topology and the energy of each node. The higher value is set, the more delay network is. We also add a variable *temp_energy_threshold*, and it starts with 0. This variable is used to store the highest *rq_min_energy* value from received RREQ messages in route finding process. In Figure 8, when the destination node receives RREQ message, it will check if this is the first time it receives the RREQ message by using broadcast ID value in the message. If this is the first time, the node will compare *rq_min_energy* field value in RREQ message with *temp_energy_threshold* value. If the *rq_min_energy* value is higher than the *temp_energy_threshold* value, the *temp_energy_threshold* value will be set to the *rq_min_energy* value. After that, the destination node will compare the *rq_min_energy* value and the *destination_threshold_energy* value. If the *rq_min_energy* value is higher than *destination_threshold_energy value*, the route satisfies the energy condition, the destination node will send RREP message to the source node. If the route does not satisfy the energy condition, it will drop the RREQ message and wait for the next RREQ messages.

In the above process, the selected route has enough energy to operate in long time. So the network's life time will be increased, and the connection lost problem will be minimized.

4 Routing Dual Criterion (RDC) Protocol

Routing dual criterion protocol is another improvement from EERS. This routing protocol is created simply by adding energy parameter in selecting route process. The route selection process using RREQ and RREP is similar to the standard EERS protocol [4],[9],[10],[11]. There are only a few small changes made in RDC.

In the RREQ message and the RREP message, we add *min_energy* field to discover energy value of nodes that these messages go through. In the old protocol, the source node will choose the route which has the lowest hop count number, so it has the energy problems described in the previous sections. In RDC, we select route based on *min_energy* parameter. The route has the lowest ratio between the hop count and the *min_energy* value will be chosen. As a result, the route with low energy is not often chosen, so the energy in network is balances. The simulation results of this algorithm will be described in the next section.

5 Simulation and Results

We use NS2 to develop our simulation because it is a popular tool. Many simulation models have been developed in NS2 and tested by many users. The AODV model used has been published on the NS2 community website and has been verified by many users. In our simulation, network lifetime, packet delivery ratio and throughput of new routing protocols RDC and ABR are compared with the original routing protocol EERS.

In the first simulation, we create five topologies with 50 nodes in an area of 500m x 500 m. The detail parameters are described as below:

Simulation time : 200 second Transmit power : 0.2818 w Initial energy : randomly from 80 to 120 joules Idle power consumption : 1 w Transmission power : 3w Receive power : 1 w Packet size : 512 bytes Packet rate : 4 packets per second

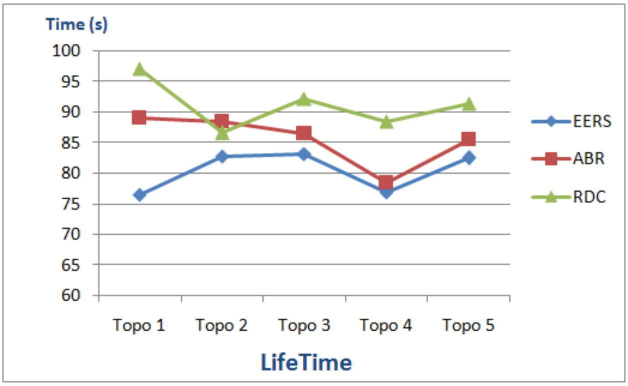

Fig. 9. Network lifetime

Let us define lifetime as the amount of time the network operate until the first node run out of energy. Figure 9 shows the lifetime of the network when using EERS, ABR and RDC routing protocols. The figure shows that the life time when using the ABR and RDC is higher than that when using EERS. In some topologies, it is 27% increase for RDC and 16.5% increase for ABR.

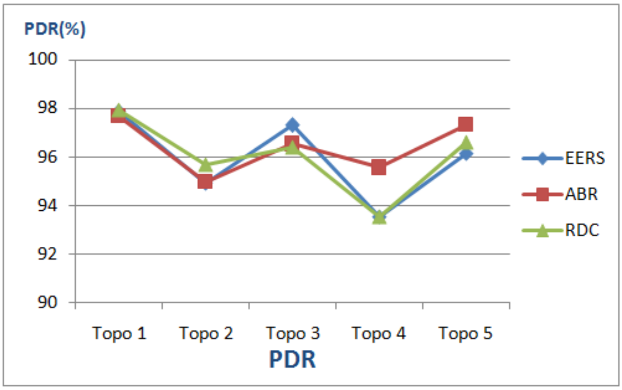

Fig. 10. Packet Delivery Ratio

Let us define the Packet Delivery Ratio (PDR) be the ratio between total messages received at the destination and the total messages sent at the source. Figure 10 shows the packet delivery ratio of network when using EERS, ABR and RDC. The diagram shows that the PDR is not much different between the three algorithms.

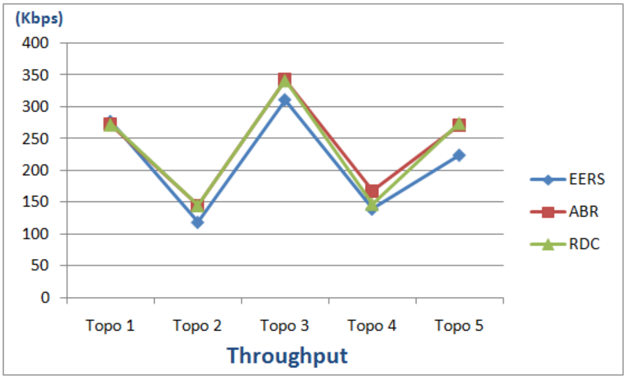

Fig. 11. Throughput

Let us define the Throughput be the total data transmission in a second. It likes bandwidth link. Figure 11 shows the throughput of network when using EERS, ABR and RDC. From this diagram we see that throughput in ABR and RDC is almost higher than in EERS. In some case throughput has increased up to 28.7% and 22.7% for ABR and RDC respectively.

In the second simulation, we create three topologies with 50 nodes, 75 nodes and 100 nodes in an area of 500m x 500m and different number of connections. The specific parameters are the same in the first simulation.

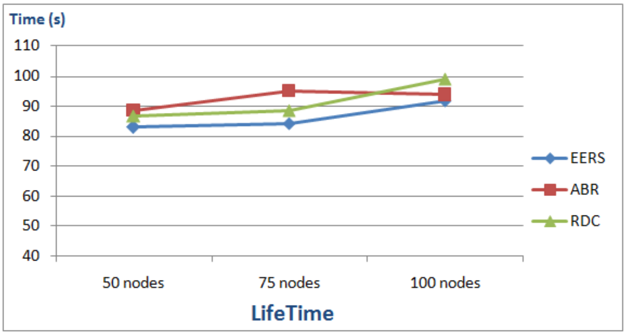

Fig. 12. Lifetime

Figure 12 shows the lifetime of network when using EERS, ABR and RC with different number of node in network. The diagram shows that the life time in ABR and RDC is still higher than in EERS.

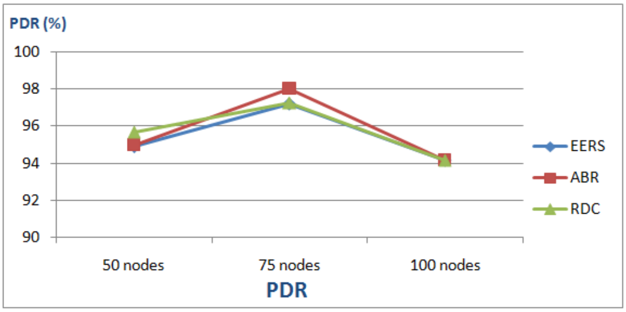

Fig. 13.

Figure 13 shows the packet delivery ratio of network when using EERS, ABR and RDC. We see that the PDR when using ABR and RDC is better than when using EERS for three topologies.

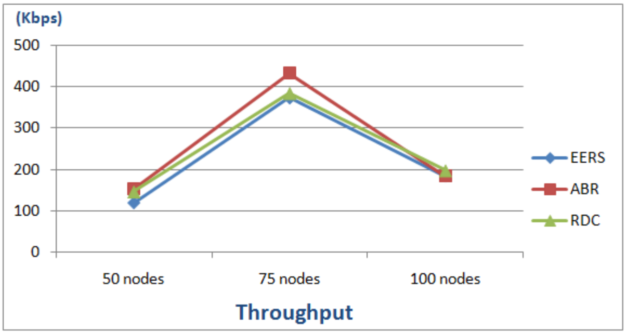

Fig. 14.

Figure 14 shows throughput of network when using EERS, RDC and ABR in three topologies 50 nodes, 75 nodes and 100 nodes. The diagram shows that network throughput when using ABR, RDC is better than when using EERS.

6 Conclusion

In this paper we propose two new routing protocols ABR and RDC. These two algorithms are improved from EERS by using energy parameter in the routing process. It modifies the route selection process selected and improves the network lifetime by avoiding the route with low remaining energy. The energy balance will prolong the lifetime of network and improve the quality of connections.

The result of simulation shows that network lifetime and throughput when using ABR, RDC is better than when using EERS. PDR is almost the same in all three routing protocols.

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