A Source Oriented Energy Efficient Dynamic Route Discovery Mechanism for Mobile Ad Hoc Networks

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ABSTRACT
Mobile ad hoc network is a collection of mobile nodes that are powered by battery for their operation. Globalized power aware routing protocols such as Minimum Battery Cost Routing (MBCR) and Min-Max Battery Cost Routing (MMBCR) selects a path considering the total transmission powers of nodes in a given route without considering the individual node transmission power and a path with nodes having maximum battery capacity for transmission of data packets from source to destination respectively. MBCR do not consider individual node battery power resulting in early network breakdown by selecting a route with less energy node. Though MMBCR considers individual node battery power during route discovery process, the route selected does not change unless any node in that route is exhausted completely resulting in network failure. This paper proposes a Source Based Energy Efficient Dynamic Route Discovery (SBEEDRD) mechanism wherein the selection of route for transmission of data is decided by the source node instead of destination node. The protocol adapts a new route dynamically before the link breaks (due to node battery exhaustion) resulting in increasing the lifetime of the network. The performance of the proposed routing protocol is compared with the existing MMBCR and EEDRD protocol. Simulation results show that the proposed protocol not only increases the lifetime of the network but also gives better throughput and packet delivery ratio, reduced delay and routing overhead.

General Terms
Mobile Ad hoc Networks, Routing Protocols, Energy Management.

Keywords
Network lifetime, battery capacity, energy level, throughput, packet delivery ratio, delay, routing overhead.

1. INTRODUCTION
Mobile ad hoc network [MANET] [1], [7] consists of mobile nodes that are connected by wireless links. MANET has a dynamic topology due to random mobility of nodes and thus the routing protocols designed for wired networks are not applicable to mobile ad hoc networks. A variety of routing protocols [3], [4], [11] were proposed and designed for MANETs. Also, nodes in a mobile ad hoc network are powered by batteries. Thus, energy efficient routing protocols [4], [10], [11], must be designed that manages the battery power of individual nodes to achieve maximum lifespan of network. In this paper, we have proposed a source based routing protocol wherein the routing decision is taken by the source node by considering the energy levels of all nodes during route discovery process, manages the battery power of nodes by reinitializing the route discovery process after transmitting certain number of data packets and adapts a new route dynamically. The rest of the paper is organized as follows. Existing energy efficient protocols are discussed in section 2. The proposed protocol is described in section 3. Simulation setup is given in section 4. Section 5 discusses the results and section 6 concludes the paper.

2. EXISTING POWER EFFICIENT ROUTING PROTOCOL: MIN-MAX BATTERY COST ROUTING PROTOCOL
Here we present a brief description of the existing power efficient routing protocols. Power efficient routing protocol such as minimum battery cost routing (MBCR) at network layer proposed by C. K. Toh [2] selects the best path with minimum battery cost or maximum battery capacity to increase the network lifetime. But this algorithm considers the summation of values of battery cost functions, thus routes containing nodes with little remaining battery capacity may be selected resulting in early network failure. C. K. Toh in [2] presented a new approach in min-max battery cost routing (MMBCR) protocol to make sure that nodes will not be overused.

If c_{it} denotes the battery cost at any time instant t, $f(c_{it})$ represents the battery cost function of node n_i and if the function reflects the remaining battery capacity of the node, then

$$f_i(c_{it})=1/c_{it} \quad (1)$$

which means that higher the value of the function f_i, the more unwilling the node to participate in the route selection algorithm. If a route contains N nodes, then the total cost of the route R_i is the sum of the cost functions of all these N nodes.

$$R_i = \min (R_j), \text{ for all } j \in A . \quad (2)$$

Here A is the set of all routes from source to destination. MMBCR selects a route based on the battery capacity of all the individual nodes. Battery cost for MMBCR is defined as

$$R_j = \max_{i \in route_j} f_i(c_{it}). \quad (3)$$

Therefore the desired route is given by

$$R_i = \min (R_j, j \in A) \quad (4)$$

where A is the set containing all possible routes. The disadvantage of this protocol is that the route selected does not ensure minimum transmission power and hence rapidly reduces the lifetime of all nodes. Thus the selected route may consume more power which actually reduces the lifetime of all nodes. Thus the battery power of nodes is not efficiently utilized. Hence there is a need to develop an energy efficient dynamic routing protocol to efficiently utilize the battery power of nodes in a mobile ad hoc network and to increase the lifetime of node and/or the network with good QoS provisioning.

3. Proposed Routing Protocol: Source Based Energy Efficient Dynamic Route Discovery Protocol

In the existing MMBCR protocol, the cost functions are calculated and stored in the route request (RREQ) packet header while the RREQ packets are sent from source to destination. The destination node receives the RREQ packets from all the possible routes and finally makes a decision of selecting a route and then sends the route reply (RREP) packet to the source node. Thus, the existing MMBCR is actually a destination oriented protocol as the decision of a route selection is made by the destination.

It actually takes some time for the route reply (RREP) packet to reach the source. The energies of the nodes in the network may change during this period. Thus, the protocol does not consider these changes in energies while selecting a route. The proposed source-based protocol overcomes this problem by calculating the cost functions in the route reply phase i.e., after receiving the RREP packets from each route; the source node selects a route for data packet transmission. The destination node receives RREQ packets through various routes and then replies to the source node immediately through the corresponding routes with RREP packets. During the process, the intermediate nodes calculate their cost functions, record the value in the RREP packet and follow the same process as was in MMBCR protocol. The source node waits for some time, receives the RREP packets and finally makes a decision of selecting the route with maximum lifetime. The route selected is used for sending the data packets. Another advantage of this Source–based protocol is that the source node receives all possible routes, stores it in the routing cache for future use. This feature is not available in MMBCR protocol. In the proposed energy efficient dynamic route discovery (EEDRD) protocol the concept of initializing the route discovery process periodically to overcome the problem of overburdening nodes in the selected route is adapted. Thus, route discovery is initialized periodically and a new route is adapted taking into consideration the battery power of individual nodes in the route. Also, to overcome the problem of routing overhead, the route discovery mechanism is initialized only after sending an optimum number of packets. Unlike EEDRD, in SBEEDRD protocol, the route selection is done by the source node instead of destination node.

4. Simulation Setup

The Network Simulator (NS-2) [5], [6] environment is used to conduct the simulation that uses the ad-hoc networking extensions provided by the University of California at Berkeley. UDP with CBR as the traffic source is used in the simulation process. A terrain size of area 1000m*1000m with varying number of nodes from 0 to 50 are used for various network scenarios. The size of the data packet used is 5000 bytes. The number of source-destination pairs is varied to change the offered load in the network.

TABLE 1. SIMULATION PARAMETERS

Parameter	Value
Terrain Size	1000*1000
MAC layer	802.11
Routing Protocols	MMBCR, EEDRD, SBEEDRD
Number of nodes	10,20,30,40,50
Radio Propagation Model	Two Ray Ground
Simulation Time	100sec
Traffic Source	CBR
Packet Size	5KB
Initial Energy	1000Joules
Tx, Rx & Idle Power Consumption	0.1W
Bandwidth	11MB
Data rate	11Mbps

5. Simulation Results

A network scenario is created as an example network and is developed in Network Animator as shown in fig.1 using the script with Tool Command Language to compare the performance of both the proposed and existing routing protocol in terms of route failure time and network lifetime. The network scenario shown in fig.1 below consists of 10 nodes. For comparing the behavior of the two routing protocols, the positions of nodes in the network is fixed. Each node is assigned an initial energy of 1.5W. The TCL script is written in such a way that initially node 4 sends data packets to node 1 after initializing route discovery process at 0.5 seconds. By the end of simulation i.e., at 10 seconds node 4 has energy level of 1.046582W and node 1 has energy level 1.360537W. The neighboring nodes which have not contributed in data transmission process but were active during this period have their residual energies as shown in fig.2.

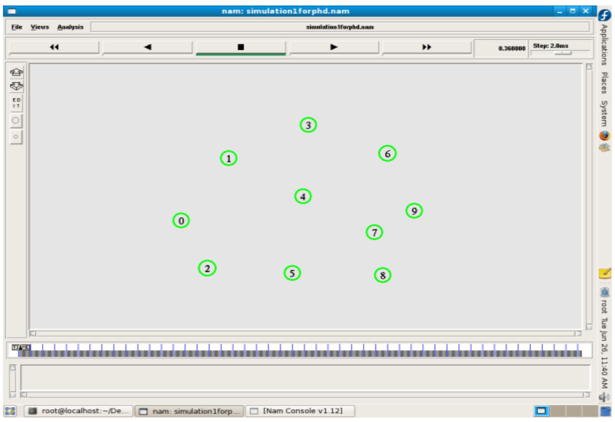

Fig. 1. **A snapshot of example network to show the route selected by MMBCR, proposed EEDRD and SBEEDRD protocol**

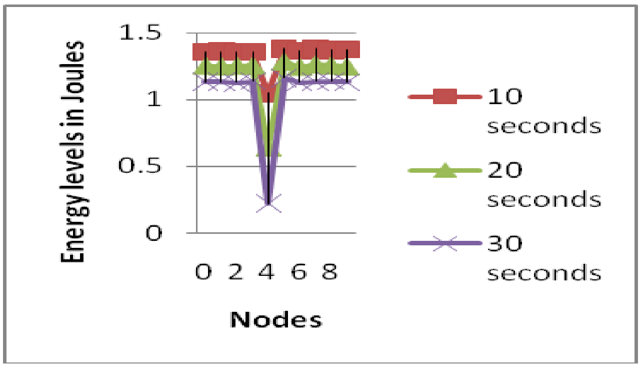

Fig. 2. **Energy levels of nodes at various pause times**

At 11 seconds, node 4 is made to transmit data to node 6 after initiating route discovery process and the simulation stops at 20 seconds. At 21 seconds, node 4 is made to transmit data packets to node 7 after initiating route discovery process. The simulation stops at 30 seconds and the energy level of each node is given in fig.2 above.

The main idea behind the above three simulations is to drain the energy of node 4 and it should be easy to observe the behavior of the three routing protocols as each node has a different energy level at a certain period.

Consider another data transmission between node 0 and node 9 i.e., node 0 is the source node and node 9 is the destination node. The route discovery process is initialized at 31 seconds.

5.1 Route selection by MMBCR

At 31 seconds the cost functions of each node is calculated from the trace file generated. MMBCR finds the maximum battery cost (i.e., minimum battery capacity) in a route, stores the value and then selects the route with minimum total cost function (i.e., the maximum battery capacity). The routing protocol selects that route with the minimum value of the total cost among all the routes that exists between the source and the destination.

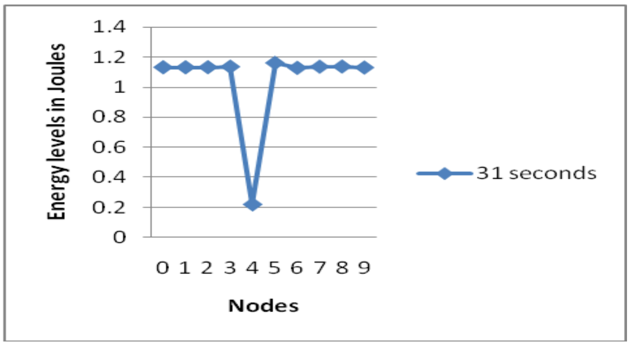

Fig. 3. **Energy levels of nodes at 31 seconds**

It also considers the individual node battery capacity apart from the total cost function in the selected route. The routes available between node 0 and node 9 are 0-1-3-6-9, 0-4-9, 0-5-7-9, 0-2-5-7-9, 0-5-8-9, etc. with respective cost functions 4.4145326, 6.298343, 3.507176, 4.38851, 3.505405, etc. Hence the route 0-5-8-9 is selected as it has the minimum cost function (i.e., maximum battery capacity) among all the routes mentioned above. Also each of the nodes in this route has maximum battery capacity compared to other nodes in other routes. For example 0-5-7-9 and 0-5-8-9 has almost same cost function but node 8 has more battery capacity and minimum cost function as compared to node 7. Thus, the route 0-5-8-9 is selected by the route discovery process. The advantage of MMBCR is that it avoids the route that has minimum battery capacity leading to enhancing the network lifetime. But the main disadvantage is that once a route with minimum cost function is selected; same route is used unless the data transmission is completed or unless the network fails due to exhaustion of less energy nodes in that route. The protocol does not consider the individual node battery. At 47.9 seconds node 5 dies resulting in route failure and partitioning of network. Node 5 as such was only an intermediate node in the data transmission process from 0 to 9.

5.2 Route selection by the proposed EEDRD and SBEEDRD protocol

In Dynamic Route Discovery (DRD) algorithm, route discovery process is initialized periodically to know the energy levels of nodes and change route accordingly. Due to continuous route discovery process, there is a chance of increasing the routing overhead. Hence the routing overhead, though consumes very less amount of energy as compared to data packets, may contribute for delay and energy consumption to some extent. To avoid unnecessary routing overhead a new mechanism is introduced in EEDRD protocol wherein the route discovery is initialized only after sending certain number of data packets. In the example network of fig.1 route discovery is initialized only after source node sends 110 data packets. Simulations were carried out for increasing number of data packets starting from 10 to 150 and the network failure time was calculated for each simulation. The optimum value of the number of data packets was found to be 110. It is observed that the network failure time increases if the route discovery is initialized after sending more number of packets i.e., if route discovery is delayed little. But at a value of 110, the network failure time is found to be maximum and for values beyond 110 the network failure time decreases. This is due to the problem of overburdening the same route for a longer period resulting in early exhaustion of node in that route. Fig.4 below gives the graph of network failure time of both MMBCR and the proposed SBEEDRD protocol. It is observed from simulation results that the network failure time for SBEEDRD is 60.5 seconds i.e., a hike of 20% compared to that of MMBCR which is only 47.9 seconds.

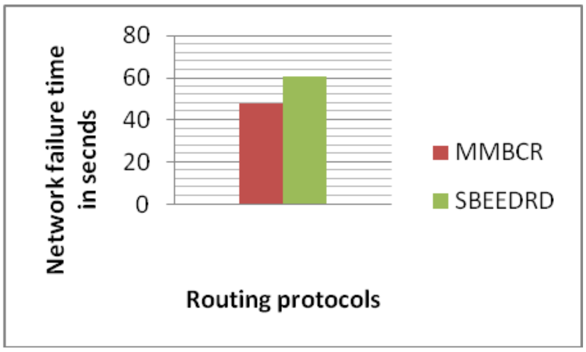

Fig. 4. **Network failure time Vs routing protocols**

Figures 5 to 9 below gives the performance comparison of MMBCR, EEDRD and SBEEDRD protocols in terms of throughput, packet delivery ratio, delay, residual energy and normalized routing load with varying number of sources.

Throughput and packet delivery ratio increases and is more for SBEEDRD and EEDRD compared to MMBCR protocol due to increase in network lifetime. SBEEDRD gives little more throughput and packet delivery ratio as compared to EEDRD protocol. Average delay is approximately same for all three protocols. A keen observation reveals that delay is more for SBEEDRD compared to EEDRD as it is a source oriented protocol. Residual energy decreases with increasing number of sources and with time but is comparatively more for EEDRD and SBEEDRD protocol compared to MMBCR. Normalized routing load is more for SBEEDRD and EEDRD protocol compared to MMBCR protocol as the number of overhead packets are increased for route discovery process.

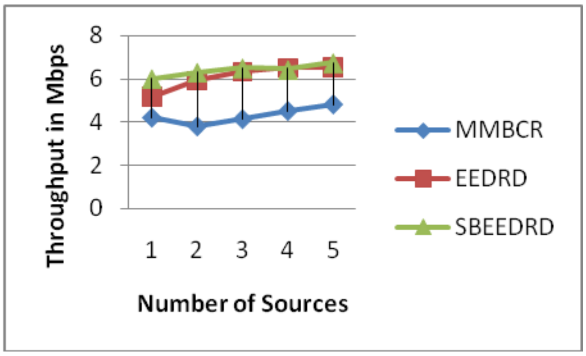

Fig. 5. **Throughput Vs Number of Sources**

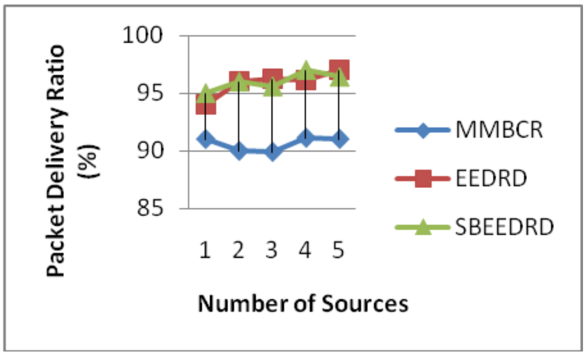

Fig. 6. **Packet delivery ratio Vs Number of Sources**

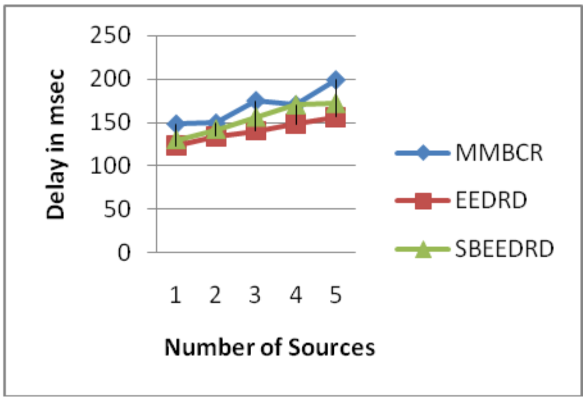

Fig. 7. **Delay Vs Number of Sources**

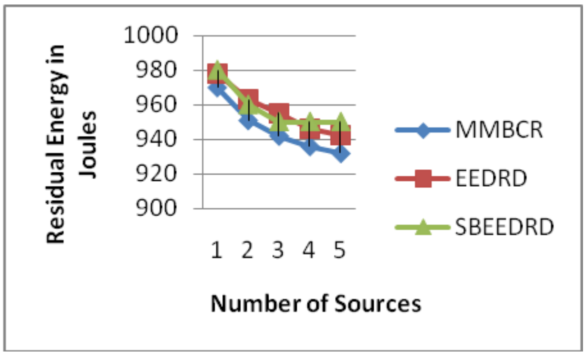

Fig. 8. **Residual Energy Vs Number of Sources**

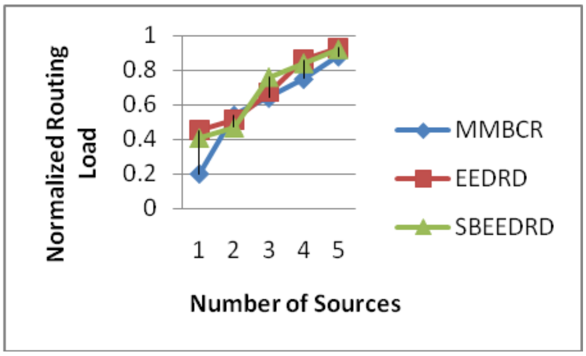

Fig. 9. **Normalized Routing Load Vs Number of Sources**

6. Conclusions

In this paper, a new energy efficient dynamic route discovery algorithm is proposed based on DRD and MMBCR in which route discovery process is initialized only after sending some fixed number of packets, updating the cost function and adapting a new route based on the energy levels of nodes in that route. This algorithm is then modified such that the route selection decision is made by the source node instead of destination node and the algorithm is named Source based energy efficient dynamic route discovery protocol. SBEEDRD protocol further improves the energy efficiency by considering the changes in energy levels during the reverse phase and selects a better route for data transmission. In MMBCR, the chances of link failure are more as the route selected is not changed unless a node in that route is terminated due to battery exhaust, DRD protocol avoids the early termination of nodes by selecting different route through route discovery process if it finds any node in that route with less battery energy. But due to periodic route discovery, DRD protocol suffers with increased routing overhead problem which in turn decreases energy levels of nodes in the network resulting in reducing its lifespan. In the proposed EEDRD protocol, routing overhead problem is reduced by initializing route discovery process only after transmitting certain number of data packets. Thus, unnecessary routing overhead is reduced resulting in minimizing the energy consumption of nodes and increasing network lifetime. In the proposed SBEEDRD protocol, by considering the energy levels of nodes in the reverse phase, an energy efficient routing decision is made by the source node which further improves the lifetime of network. Thus, from simulation results we conclude that the new routing mechanism provides an efficient way of utilizing the energy of nodes. The performance of the protocols is evaluated using throughput, packet delivery ratio, end-to-end delay, average residual energy and normalized routing load. These metrics are evaluated and compared with existing protocol by varying the number of sources. SBEEDRD protocol achieves high throughput and packet delivery ratio and less routing overhead as compared with EEDRD and MMBCR protocols.

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