A Multipath Energy-Efficient Routing Protocol for Ad hoc Networks

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***Abstract*—Ad hoc networks consist of mobile nodes which have no fixed infrastructure. The mobile nodes have limited battery energy, so it is very important to use energy efficiently in ad hoc networks. In order to maximize the lifetime of ad hoc networks, packet should be sent via a route that can avoid nodes with low power. A lot of routing protocols about ad hoc networks have been proposed. But most of them build and rely on single route for each data session. Multipath technique, however, can improve the mean time to node failure and balance the load in ad hoc networks. Accordingly, this paper proposes a new multipath routing protocol, MEER (Multipath Energy-Efficient Routing) that includes the advantages of on-demand protocols, also prolongs the network lifetime by using a rational power control mechanism.**

I. INTRODUCTION

A mobile ad hoc network (MANET) [1] is a collection of mobile nodes without any base station or infrastructure support. Mobile nodes directly communicate with other nodes within a wireless coverage or indirectly communicate via multi-hop routes. Because ad hoc networks can be easily deployed, they are developed in many applications such as military, sensor networks, disaster recovery and many kinds of personal area networks [2].

In an ad hoc network, the links are wireless and thus have many constraints, including the limited energy of the nodes, bandwidth and unpredictable node connectivity. Moreover, all nodes can be mobile, so the network topology changes frequently. Consequently, routing protocols play an important role in ad hoc networks. Routing protocols in ad hoc networks are generally categorized into two groups, table driven and on-demand protocols. Instead of periodically exchanging route messages to maintain route table, on-demand routing protocols discover routes only when a node needs to send data to a destination. For improving the effective bandwidth of communication, balancing the traffic and increasing the delivery ratio of the packets, multipath routing protocols have been proposed in [3], [4], [5], [6] and [7]. Although these protocols build multiple paths to a destination by using different approaches, they are not much concerned with the battery-power of nodes in the routes. If some nodes are energy constrained, such protocols can have adverse effects on the network. For example, if a node with low power forwards a lot of packets, its energy will be depleted and not be able to function as an intermediate node. As the number of such nodes increases, the network will be more likely to be partitioned.

In this paper, we propose a new ad hoc routing protocol called MEER (Multipath Energy-Efficient Routing) based on the SMR (Split Multipath Routing) [7] protocol that maintains the advantages of on-demand protocols while providing energy efficiency. It does not only protect the nodes from overly consuming the energy compared to the other nodes in the network, but also prolongs the lifetime of the network.

The remainder of this paper is organized as follows. In section 2 we briefly summarize the SMR protocol and some power-aware routing protocols. Section 3 describes the proposed protocol MEER. Section 4 evaluates the performance of MEER and some final conclusions are given in section 5.

II. RELATED WORK

A. SMR Protocol

Multipath routing protocols in ad hoc networks have been proposed in [3], [4], [5] and [6]. Although these protocols build multiple routes to a destination on demand, there will be common nodes among these routes. The traffic is not distributed into multiple routes. So the SMR (Split Multipath Routing) [7] protocol was presented by Sung-Ju lee and Mario Gerla, it builds maximally disjoint paths. Data traffic is split into multiple routes to avoid congestion and use network resources efficiently.

SMR is an on-demand routing protocol that builds multiple routes using request/reply cycles. When the source wants to send data to a destination but no route information is known, it floods the Route Request (RREQ) message to

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the entire network. Instead of dropping every duplicate packets that traversed through a different incoming link than the link from which the first RREQ is received, and whose hop count is not larger than that of the first received RREQ. After this process, the destination waits certain duration of time to receive more RREQs and learn all possible routes. It then selects the route that is maximally disjoint to the route that is already replied. The maximally disjoint route can be selected because the destination knows the entire path information of the first route and all other candidate routes.

However, the SMR protocol has two disadvantages. In SMR protocol, the intermediate nodes need to transmit more RREQ packets in the route discovery process. This will give rise to the congestion of the network. In addition, it is not concerned with the energy of each node in the route. The nodes with low power also need to forward packets, so the energy of such nodes will be exhausted earlier than the other nodes. If nodes stop their operations, it can result in the network partitioning or interrupt communication. Figure 1 illustrates this problem (the number in the figure denotes the energy of each node).

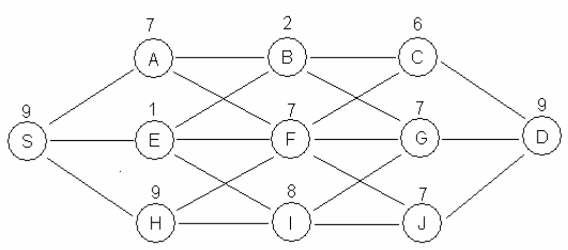

Figure 1. A network illustrating the disadvantage of SMR

According to the routing scheme of SMR, it is very possible to select two routes which include node B or E, such as S-A-B-C-D and S-E-F-G-D. So the node B and node E will exhaust their energy much earlier than the other nodes and the network lifetime will decrease.

B. *Power-Aware Routing Protocols*

Conventional routing protocols for ad hoc networks select the routes based on the minimum hop count. Such minimum hop routing protocols can use energy unevenly among the nodes, so that some nodes expand all their energy earlier, thereby reducing the lifetime of the network as indicated in section 1. Recently, several power-aware routing protocols have been proposed in [8], [9] and [10]. Among them, the MBCR (Minimum Battery Cost Routing) [8] protocol tries to use battery power evenly by using a lost function which is inversely proportional to the remaining battery power. The total cost for a route is defined as the sum of costs for the nodes that are the components of the route, and MBCR selects a route with the minimum total cost. It seems that this approach extends the lifetime of the network because it chooses the route composed of the nodes with high battery power. However, since it only considers the total cost, the remaining energy level of an individual node may hardly be accounted for. That is, the route can include a node with low power and other nodes with plenty of power.

Therefore, to prolong the lifetime of an individual node, MMBCR (Min-Max Battery Cost Routing) [9] introduces a new path cost which is defined as $R_j = max_{i \in route\text{-}j} f(B_i)$, and it selects the route with the minimum path cost among possible routes. Since this metric takes into account the remaining energy of individual nodes instead of the paths total energy, the energy of each node can be used evenly. However, this metric can build the route with an excessive hop count and consume a lot of total energy.

CMMBCR (Conditional Max-Min Battery Capacity Routing) [10] was proposed to enhance MMBCR, it tries to balance the total transmission power consumption and the individual node power consumption.

III. THE PROPOSED MEER PROTOCOL

The proposed MEER (Multipath Energy-Efficient Routing) protocol, based on SMR (Split Multipath Routing) [7] protocol, considers the energy consumption when establishing a route. The MEER protocol consists of three phases, i.e., 1) the route discovery phase in which the source node searches for the routes to the destination node, 2) the route selection phase in which the proper routes are selected among several candidate routes and 3) the route maintenance phase.

A. *The Routing Discovery Phase*

In MEER, the route discovery phase in which the source is finding energy-efficient routes is similar to that of SMR. If the source node needs a route to the destination but no route information is known, it floods the Route Request (RREQ) message to the neighborhood nodes. Unlike the SMR, besides the source ID and a sequence number that uniquely identify the packet in a RREQ, two fields named *minP* and *aveP* are appended in the RREQ packet header to record the minimum energy and average energy of nodes in a path respectively.

In order to avoid overlapped route problem, intermediate nodes do not drop every duplicate RREQs and forward duplicate packets that traversed through a different incoming link than the link from which the first RREQ is received, whose hop count is not larger than that of the first received RREQ. For decreasing the flooding of the RREQs, we limit the times which a node forwards the duplicate RREQs can not surpass two. In other words, if a node has forwarded two duplicate RREQs, it will not forward the RREQs which have the same ID again, even though the hop count is not larger than the former two.

When an intermediate node other than the destination receives the RREQ and it is the neighborhood node of the source, it appends its remaining energy to the *minP* field and *aveP* field respectively. Otherwise, any intermediate node that receives the RREQ other than the destination compares its own remaining power with the value in the *minP* field. If the former is smaller than the latter one, it changes the value of the *minP* field with the value of its remaining energy. Otherwise, it does not change the *minP* field in the RREQ header. Additionally, the node calculates the average remaining energy (P_{new}) of new route that includes itself as following equation.

$$P_{new} = \frac{P_{old} \times N + P_i}{N + 1} \tag{1}$$

Where P_{old} is the value in the *aveP* field of the RREQ received by the intermediate node, P_i is its own remaining energy and N is the number of hops that the RREQ packet has passed. After above process, the node appends its ID and re-broadcasts the RREQ until the RREQ arrives to the destination.

In addition, intermediate nodes are not allowed to send Route Reply (RREP) messages back to the source even they have route information to the destination, so each node uses less memory.

B. *The Route Selection Phase*

Similar to the SMR, the destination selects two routes that are maximally disjoint in our algorithm. When receiving the first RREQ, the destination records the entire path but does not send a RREP to the source. Then the destination waits a certain duration of time to receive more RREQs and learn all possible routes. After that, the destination selects the first route based on the following strategy.

- First, the destination selects a route which has the biggest *minP* value from all possible routes.
- If there are some routes have the same *minP* value, the route which has the biggest *aveP* value will be selected.
- If there are several routes have both the same *minP* value and the same *aveP* value, the route with the smallest hop count will be selected.
- If still there are several routes have the same *minP* value, *aveP* value and the hop count, the destination selects one from them randomly.

After selecting the first route, the destination records the entire path and sends a RREP message to source via this route. It then selects the route that maximally disjoint to the first one. The maximally disjoint path can be selected because the destination knows the entire path information of the first route and all other candidate routes. If there are more than one route that maximally disjoint with the first route, the destination selects the second route according to the above mechanism. The destination then sends another RREP to the source via the second route selected.

C. *The Route Maintenance Phase*

Because a link of a route can be disconnected due to mobility, congestion and packet collisions, it is very important to recover the broken routes immediately. In MEER, if an intermediate node detects a link break, it transmits a Route Error (RERR) message to the upstream direction of the route. After receiving the RERR message, the source removes every entry in its route cache that uses the broken link. If only one of the two routes of the session is invalidated, the source uses the remaining valid route to deliver data packets. If the source has not any valid route in their cache, then the source node begins the route discovery phase and searches for proper routes again.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed MEER (Multipath Energy-Efficient Routing) protocol in various environments. For comparison with SMR (Split Multipath Routing) [7], a typical multipath routing protocol, and MMBCR (Min-Max Battery Cost Routing) [9], a power aware ad hoc routing protocol, are also implemented. MMBCR is modified to use the route discovery and route maintenance mechanism of on-demand routing protocol DSR (Dynamic Source Routing) [11].

Our simulations are run using ad hoc networks of 50 nodes, each node uses IEEE 802.11 standard MAC layer under a nominal bit rate of 2 Mbps. The max radio range is 100m. Each node in the network moves according to the random waypoint model. In this model, each node chooses a random destination and moves toward it with a constant speed chosen uniformly between zero and a maximum speed. When the node reaches the destination, it chooses a new destination and begins moving toward the destination after a pause time. In our simulation, we choose maximum speed of 5m/sec. The pause time is a simulation parameter. The nodes have the identical mobility pattern in all experiments. In this experiment, we use two sources to generate CBR traffic with UDP packets at 5packets/sec, and such packet size is 1024 bytes. Mobile nodes are free to move in a 1000m×1000m topology boundary and the simulation time of 100 sec.

We measure the average remaining energy for the nodes on the selected path at first. For this simulation, the energy values spent when nodes receive and transmit a packet are set to 0.9W and 1.2W respectively. The packet processing energy is typically much smaller than that required for packet transmitting, therefore, the paper omitted the energy used for processing the packets. The initial energy of each node was set to 20J and some randomness provided, as in the following equation.

$$IniE = E[IniE] \times (1 \pm \alpha) \tag{2}$$

Where $E[IniE]$ is the average initial energy and α is a random value. This simulation provided 10%-50% randomness. For example, when the average initial energy is 20J and the randomness is 10%, then each node has 18-22J initial energy.

Figure 2 shows the average remaining energy for the nodes on the selected paths when using each protocol. As such, SMR and MMBCR have a lower remaining energy than MEER. As the MEER's route discovery procedure reduces the reconstructions due to node energy shortages.

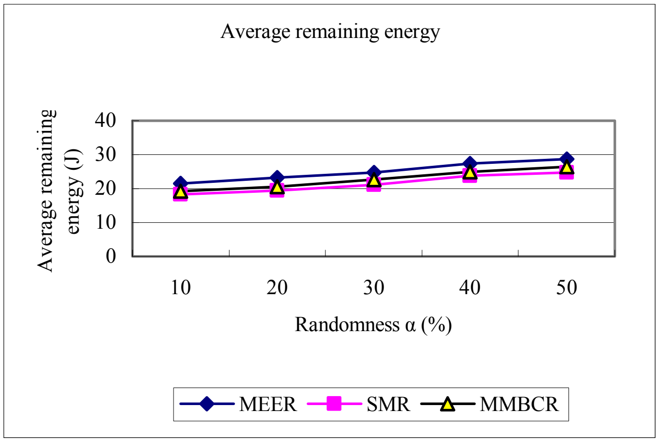

Figure 2. Average remaining energy of select paths

The second experiment evaluates the total energy consumption in the ad hoc network during the transmission of 5000 data packets. The total energy consumption is the sum of the energies involved in the route discovery and maintenance, error recovery and packet transmission of 5000 packets through all the communicating nodes. The average energy for all nodes was 20J. Figure 3 shows the total energy consumption when the node pause time is varied.

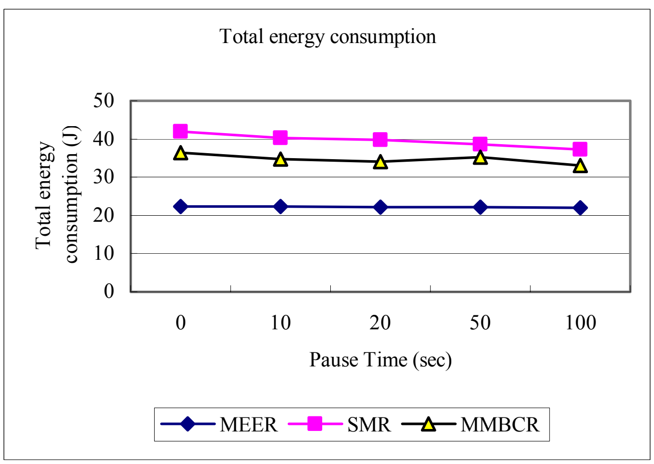

Figure 3. Total energy consumption in the network

From the figure we can see that the energy consumption of MEER is much smaller than that with SMR and MMBCR. It is because that the MEER builds two paths that only consist of nodes with much high power. It decreases the route reconstructions caused by the energy exhaustion of the node.

The last experiment measures the average packet delivery ratio, which is calculated by dividing the number of packets received at the destination by the number of packets sent from the source during the simulation time. In this experiment, each node's energy was 20J. Figure 4 shows that MEER, SMR and MMBCR have a high delivery ratio, because all three protocols are based on an on-demand metric. But the packet delivery ratio for MEER is higher than that for SMR and MMBCR, as MEER uses two paths in terms of energy hence enhances the stability of the routes.

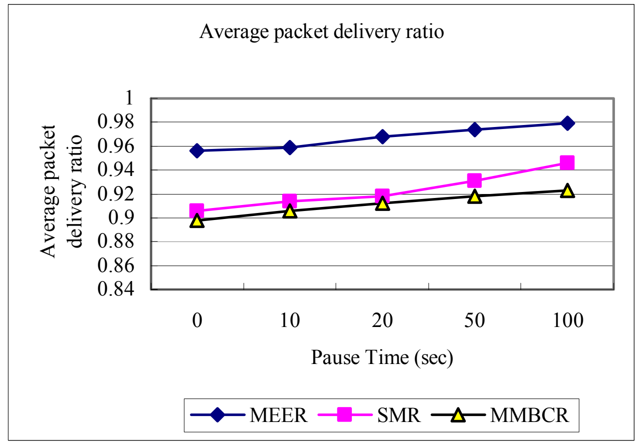

Figure 4. Average packet delivery ratio

V. Conclusions

In this paper, we proposed a novel multipath routing protocol named MEER (Multipath Energy-Efficient Routing). In MEER, routing policy concerning the energy efficiency on the basis of SMR has been proposed. The high efficiency of packet delivery could be achieved by determining the participation on routing according to the present energy leftover, because the excessive energy consumption of the particular nodes with low energy is avoided in ad hoc networks. So it prevents the early network partition and extends the network lifetime. In addition, we limited the number of routes to two in this study, but it can be extended by choosing more than two routes from a source to a destination.

The performance of the proposed MEER protocol has been studied through a simulation and compared with the existing SMR and the power-aware MMBCR protocol. The simulation results showed that the proposed ad-hoc routing protocol MEER was outstanding in terms of the energy consumption, data delivery ratio, path stability and reliable data transmission.

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