Power-aware Route Maintenance Protocol for Mobile Ad Hoc Networks

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Abstract— **Most power-aware routing protocols proposed for mobile ad hoc networks are "proactive" protocols where power consumption state of nodes are exchanged periodically among nodes. For on-demand reactive routing protocols, however, new routes have to be acquired periodically to better reflect the current power states of nodes. In this paper, we propose a power-aware route maintenance protocol in order to prolong the network lifetime, when applied to on-demand reactive routing protocols without periodic route recovery. This is achieved by using two threshold power levels to evenly distribute power dissipation among nodes. Through simulations, we proved that our protocol can be applied to on-demand routing protocols without the need to perform periodic route recovery.**

Keywords—**Mobile Ad Hoc Networks, Power-Aware Routing, Threshold, Lifetime of Nodes**

I. Introduction

Mobile ad-hoc networks (MANET) [1] have no fixed infrastructures. All nodes communicate with neighboring nodes via their wireless interfaces, i.e., the base station is missing. To achieve peer-to-remote communication, multi-hop communications is needed. Hence, some intermediate nodes should participate in forwarding packets when the source-destination pairs are not directly within the radio range of each other. Developing essential protocols (at different layers, e.g., MAC and network layers) for MANETs has been an active research activity in the past few years. Until recently, many proactive and reactive routing protocols have been proposed [2]. In proactive schemes, nodes maintain their routing tables for all possible destinations irrespective of the need for routes. However, in reactive schemes, routes are acquired based on-demand by the source. Therefore, it does not have to maintain routing tables when there are no desires for routes.

A critical issue in MANETs is that nodes have limited power availability over time. Since several earlier and well-known routing protocols had overlooked the need to consider power-constraint, there has been an evolution of new power-aware routing protocols [4] [5] [6] [7]. Some of these routing protocols focus on efficient power utilization, along with other different goals [6] [8] [9] [10].

This work was supported in part by the Brain Korea 21 project of Ministry of Education, in part by the National Research Laboratory project of Ministry of Science and Technology, and in part by the Post-doctoral Fellowship Program of Korea Science and Engineering Foundation (KOSEF).

The MTPR (Minimum Total Transmission Power Routing) protocol [8] was initially developed to minimize the total transmission power consumed per packet, regardless of the remaining battery power of nodes. Since the transmission power required is proportional to d^{α}, where d is the distance between two nodes and α between 2 and 4 [3], MTPR prefers routes with more hops having short transmission ranges to those with fewer hops but having long transmission ranges, with the understanding that more nodes involved in forwarding packets can increase the end-to-end delay. Since MTPR does not consider the remaining power present in nodes, some nodes with low residual battery capacity can easily run out of capacity if they participate in forwarding packets. Therefore, the MMBCR(Min-Max Battery Cost Routing) protocol [9] scheme was suggested to consider the remaining power of nodes as the metric in order to extend the lifetime of each node.

MMBCR allows nodes with high residual power to participate in routing more often than nodes with low residual battery capacity. Note that in every possible path, there exists a weakest node which has the minimum residual battery capacity. Hence, MMBCR tries to choose a path whose weakest node has the maximum remaining power among the weakest nodes in other possible routes to the same destination. However, MMBCR does not guarantee that the total transmission power is minimized over a chosen route.

To address this problem, the CMMBCR(Conditional Max-Min Battery Capacity Routing) protocol [10] scheme was proposed. The CMMBCR approach is a hybrid approach combining the MTPR and MMBCR schemes. It takes into consideration both total transmission energy consumed by routes per packet and the remaining power of nodes. However, in order to apply these power-aware routing protocols to MANETs, all source nodes should periodically obtain new routes that take into account the continuously changing power states of network nodes. In other words, some proactive routing protocols should be used. This requires all nodes to maintain the route and update power information of nodes regardless of their demand for routes. Alternatively, this could take the form of a periodic beacon for on-demand routing protocols. Note that many research papers so far have revealed the weak performance associated with proactive routing protocols, which is mainly due to the overhead incurred for maintaining routes [2].

To apply power-awareness to on-demand reactive routing protocols, all source nodes have to perform periodic route recovery in order to find a new power-aware route even when there is no route breakage.

In this paper, a new power-aware route maintenance protocol is introduced which can be applied to on-demand routing protocols without the need of periodic route recovery. Whenever all the source nodes should find their routes, the CMMBCR protocol is utilized to consider both minimizing the total transmission power and prolonging the lifetime of each node by taking into account the remaining battery power. Furthermore, when the remaining power of nodes participating in forwarding packets reaches a dangerous level before power breakage, the protocol allows the selected connections through the node to find other alternative routes to avoid the power over-usage of the node.

The rest of this paper is organized as followings. In Section II, we briefly describe the CMMBCR scheme which our protocol is based on. In Section III, the detailed protocol for power-aware route maintenance is given. Section IV presents performance evaluation with some simulation results. Finally, this paper is closed with some concluding remarks in Section V.

II. Conditional Max-Min Battery Capacity Routing (CMMBCR)

When all nodes in some routes possible have sufficient remaining battery capacity(i.e., above a threshold γ), a route with minimum total transmission power among these routes is chosen. Since less total power is required to forward packets for each connection, the relaying load for most nodes can be reduced, and their lifetime will be extended. However, if all routes have nodes with low battery capacity (i.e., below the threshold), a route including nodes with the lowest battery capacity must be avoided to extend the lifetime of these nodes. We define the battery capacity for route r_j at time t as: $R_j(t) = \min_{\forall n_i \in r_j} c_i(t)$.

Given two nodes, n_a and n_b, this mechanism considers two sets Q and A, where Q is the set of all possible routes between n_a and n_b at time t, and A is the set of all possible routes between any two nodes at time t for which the condition $R_j(t) \geq \gamma$ holds. The route selection scheme operates as follows: if all nodes in a given paths have remaining battery capacity higher than γ, choose a path in $\mathrm{A} \cap \mathrm{Q} \neq \emptyset$ by applying the MTPR scheme; otherwise select a route r_i with the maximum battery capacity (i.e., MMBCR is applied).

III. Description of Proposed Protocol

In the previous sections, we summarized the schemes proposed to reduce power consumption and to evenly distribute power consumption to each node. In particular, CMMBCR does consider both minimum transmission power and remaining battery capacity. However, when applied to ad hoc on-demand routing protocols that do not perform periodic route recovery when there is no route breakage, CMMBCR alone cannot distribute power consumption evenly to each node. This is so because CMMBCR is applied only when setting up a new route and it does not reflect power consumption rate of each node during active data sessions. For instance, one specific node could be selected as a relaying node for many source-destination connections at the same time. Under such a situation, its power drain rate is more severe than the other's and it runs flat easily. To avoid this problem, we need to introduce route maintenance procedures so that the battery consumption rate of nodes can be evenly distributed, thereby accomplishing the goal of power-aware routing.

A. Protocol Overview

In CMMBCR, we face the dilemma of choosing the threshold γ. If we try to determine γ as an absolute value(e.g., X Joules), CMMBCR gets the nodes with the residual battery capacity less than X Joules to participate in the MMBCR procedure, which can cause more nodes to spend their energy due to the usage of longer route. However, if we allow nodes with residual battery capacity less than X Joules to participate in the MTPR procedure when the traffic load is light, we can save more energy consumption in the overall network than with CMMBCR. Otherwise, if we define γ as the relative percentage of the remaining battery of each node(e.g., Y %), then there is no way to efficiently determine γ in the situation where there is no centralized server that has the knowledge of energy status of all nodes in the mobile ad hoc network.

In this paper, when acquiring an initial route, CMMBCR is adopted in a way where the source is allowed to specify the minimum requirement(γ) of the remaining power of nodes over the route according to its application type. So, among paths over which nodes have their remaining powers above γ, the route with the minimum total transmission power is selected. Here, it is assumed that nodes can always determine their remaining battery capacity.

To perform route maintenance with consideration of the remaining power of nodes during a data session, two battery thresholds, namely: (a) selective-victim-search-zone (SVSZ), and (b) forced-victim-search-zone (FVSZ) are defined in this work. The SVSZ is used to signify that the battery of a node is running low, but is still adequate to keep it running. However, without taking a prompt action such as relieving the node of routing activities, the node will die soon because it is forwarding the data packets from so many connections and its battery capacity can reach a very low level up to the FVSZ very quickly. In this case, the node should attempt to select a connection for which it continues to forward packets and a connection for which it finds another route (if any). If alternative paths do not exist, the SVSZ node continues to forward packets as usual, resulting in reaching another lower threshold, FVSZ. Below FVSZ, the battery is low enough to decline forwarding all packets for others. All connections passing though this node should therefore find their alternative routes. This remaining power below FVSZ will be reserved for data packets that will be generated when the node itself acts as the source node. From this context, if the remaining battery capacity of a node is above the SVSZ threshold and the requested battery parameter γ of a connection, it continues to relay the packets. Meanwhile, if the current battery capacity of a node goes below the value γ, the connection should be notified to re-route because the route can no longer satisfy the requested battery capacity. The source node of the connection should find alternative routes with its own adjusted γ value.

When a battery capacity of node reaches between two thresholds, SVSZ and FVSZ, we should selectively choose a victim for which the re-route is required to evenly distribute the overall power consumption. Some connections that have used up the relaying node's battery more than the average battery consumed by each connection become the candidates of victim. The reason we adhere to this selection rule is that it allows fair use of the capacity at this node among all connections traversing through it. However, the SVSZ node will continue to forward packets for the source while the victims try to find alternative routes. Figure 1 describes our power-aware route maintenance algorithm.

B. Victim Selection Rule

Upon entering the SVSZ state, a node must select a connection and notify it to find another path to distribute its power consumption evenly to the other nodes. This means that we have to choose one of the connections with a specific condition.

We define two selective conditions: (a) "definitely selected" and (b) "possibly selected". If the current battery capacity of a node goes below the value γ which a source requested as a parameter when setting up a new route, the source of this connection should be notified to re-route. We call this type of selective choice "definitely selected". "Definitely selected" is also applied when the current battery capacity of a node enters FVSZ status. In other words, all the connections going via the node below FVSZ status should be notified to perform re-route.

As for the "possibly selected" rule, when the current battery capacity of a node is between SVSZ and FVSZ, we need to select one connection in a certain condition to re-route. As for the selection criteria, we choose those that have used up the relaying node's energy over the average energy expenditure among connections. This condition is to provide fair use of the capacity at the node among all the connections passing through it. This can be determined by two schemes as described below.

1. **Traffic Load:** The routing protocol monitors the source-destination pairs with some discrete port numbers in the packet to distinguish flows and to keep count of how many packets are served for each flow. Therefore, flows which have been served over the average service rate can be candidates for the victim.

2. **Energy Expenditure:** The routing protocol also monitors and keeps the amount of energy expenditure of each packet which is caused by each operational activity (transmission and reception) of each flow with the help of network interface card. Therefore, the flows which have spent over the average energy consumption of each flow can be candidate for the victim.

In this paper, we used the traffic load scheme to select the victims for simplicity of implementation. Besides two schemes, we plan to compare the performance of other candidate schemes in the future.

Once the victim is selected, the relaying node sends a selective victim message packet back to the source of selected connection as a warning that it should find another route in place of the existing route that does not include a SVSZ state node. Note that the SVSZ node will continue to relay packet for the source until it finds another route. If the alternative path does not exist, the residual battery of the node will keep depleting until it finally enters FVSZ state. In this state, the node stops relaying packets for others and sends a forced victim message packet back to every source of the connections via this node.

C. Illustrative Examples

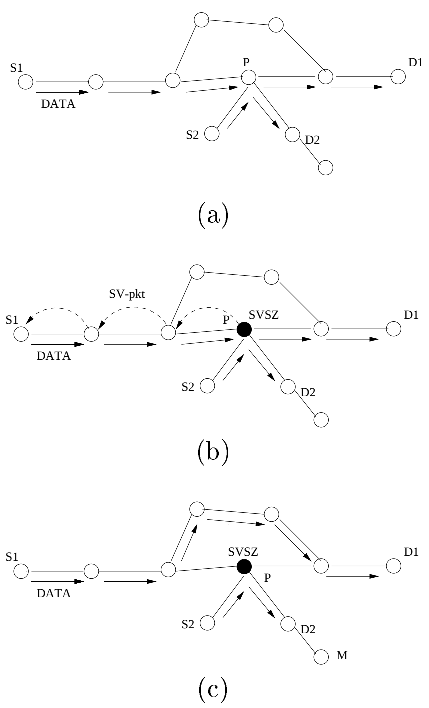

Fig. 2. Selective-victim-select-zone

Figure 2 shows the established routes for a given source S1,S2 and destination D1,D2 pair, respectively using the power-aware route maintenance described before. Suppose that the connection between S1 and D1 started before the

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 C : Capacity of the forwarding node's remaining battery.
 γi : the minimum requirement of the remaining power of nodes over the route,
        which is specified by connection i.
if (C < γi )
            The connection i should be notified to re-route.
else if ( remaining battery capacity C > SVSZ )
            Relay packet.
else if ( SVSZ ≥ C > FVSZ )
   {
            Notify sources SELECTIVELY to re-route
                 according to our Victim Selection Rule(Sec.III.B);
            Still relay packets;
   }
else if ( FVSZ ≥ C )
   {
            Stop relaying packets;
            Notify all connections to re-route;
            Only used to send or receive within one hop;
}
```

Fig. 1. Power-Aware Route Maintenance Algorithm.

other connection does. As shown in the figure, each connection goes via node P at the same time. So, the battery consumption rate of node P is more aggressive than the other. Upon entering the SVSZ state, node P has to determine whom to choose to request to re-route. Suppose that the connection between S1 and D1 consumed more energy than the other one, node P selects S1-D1 pair as a victim. Node P sends selective victim message packet (SV-pkt) back to the source S1 to give it a warning to find another route. But node P will continue to route data packets for the S1 until S1 finds another route. This is shown in Figure 2.(b). Upon receiving SV-pkt, the source S1 starts using alternative route after obtaining a new one through a route discovery. Note that node P does not participate in this route discovery by not forwarding Route Request packet after node P receives it, thus guaranteeing that it will not be included in the new route. Figure 2.(c) shows the new route that the S1 has obtained via a route discovery to the destination D1.

Figure 3 depicts such a scenario for a node going into the FVSZ state from the SVSZ state. The node P which is in SVSZ state still relays data packet for source S2. The battery level of node P will continue to be depleted until it reaches the FVSZ state (as shown in Figure 3.(a)). At this state, it has no choice but to send back a forced victim message packet(FV-pkt) to the source S2 telling that it refuses to participate in forwarding its data packets to reach the destination D2 as shown in Figure 3.(b). The source S2 receives FV-pkt and cannot find a new route and let us assume that node M has moved from its original location. At this point, any more data packets that the FVSZ state node encounters from S2 will be dropped. The FVSZ state node will refuse to participate in any other route discoveries and Figure 3.(c) shows the final route was discovered, which does not include both SVSZ state node and FVSZ state node.

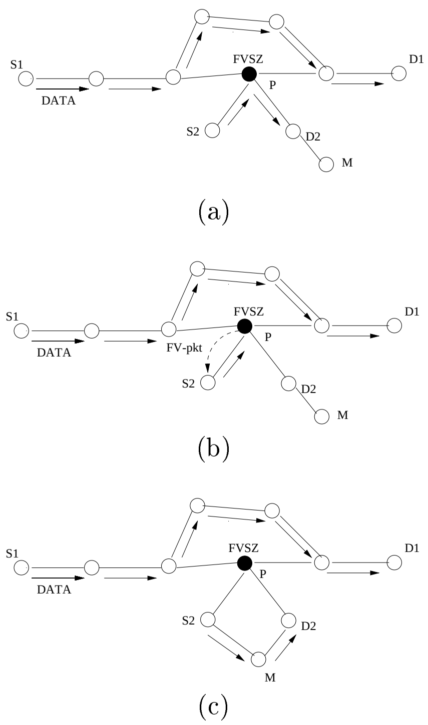

Fig. 3. Forced-victim-select-zone

IV. Performance Evaluation

In this paper, we investigate the performance of our route maintenance protocol against MTPR and CMM-BCR, which are applied not when the source periodically performs route recovery, but when the source nodes try to find alternative paths according to route failure. Particularly, since only a few actual network interface cards allow a limited number of discrete power levels, we implemented nodes with a fixed transmission range (250 meters). This is supported mostly by current network cards. Hence, this means that MTPR selects the shortest path among possible routes, thus behaves exactly like the protocol using minimum-hop paths. Theoretically, only when all nodes are capable of adjusting their transmission ranges according to the distance between nodes, MTPR can reduce the total transmission power consumed per packet by utilizing routes with more hops having shorter transmission ranges.

A. Simulation Setup

We simulated our protocol after modifying the DSR protocol [12] to accommodate the route selection mechanisms of MTPR and CMMBCR by using ns-2 simulator with CMU wireless extension [11]. However, other on-demand ad hoc routing protocols such as ABR and AODV [2] are also applicable. For on-demand routing protocols, the source node performs route recovery (when the route breakage is caused by power outage or node movement), by MTPR and CMMBCR as the route selection schemes. When source nodes attempt to find the best route, they could select the best one among the cached routes returned by the destination nodes through the route selection criteria. Moreover, if some intermediate nodes respond to the route requests with their cached routes when performing the route discovery, we cannot obtain the expected route because the cached routes do not represent the current state of power consumption of nodes. Hence, we avoided some route cache optimization techniques performed by intermediate nodes as in the DSR protocol.

Our proposed protocol is implemented with both the selective-victim-search-zone state and forced-victim-search-zone state as described before.

As for node mobility, the well-known random waypoint model is used. In this model, the motion is characterized by two factors: (a) maximum speed, and (b) pause time. Each node starts moving from its initial position to a random target position selected inside the simulation area. The speed of nodes is uniformly distributed between 0 and the maximum speed. When a node reaches the target position, it waits for the pause time, then selects another random target location and moves again. 50 mobile hosts move around a rectangular space of size 670 m × 670 m square. We used 10 conversations with source and destination nodes selected randomly. The maximum speed of nodes is 10 m/sec.

We measured our protocol performance in terms of: (a) total number of data packets delivered (measured as the total number of data packets delivered from a source to a destination) , (b) fraction of nodes in FVSZ state (measured as the fraction of nodes in the network whose battery level is at or below the threshold of FVSZ), and (c) total number of control packets used for route maintenance (measured as total number of control packets needed to route data packets. In the case of power-aware algorithm performance, SV-pkt and FV-pkt are also counted.).

For the two battery threshold levels, we used values of 45 % and 20 % of the initial battery level for the SVSZ and FVSZ thresholds, respectively. We assumed that a node spends 0.0002 units of energy for transmitting and 0.0001 unit of energy for receiving a packet. To make the measurement simpler, we used the same energy values regardless of the size of packet. Batteries were initialized to 5 units of energy. Finally, for simplicity of simulation, we also start the initial minimum requirement (γ) of remaining power for each connection with 2 units of energy. When needed to adjust the minimum requirement of a γ value, the source chooses some random value between the previously selected one and FVSZ as a new γ value.

B. Simulation Results

With the original MTPR (without periodic route recovery applied), the acquired shortest path will continue to be used until some route breakage is incurred due to movement or power breakage. In either case, the source node will be notified of the route breakage and tries to find alternative routes. Meanwhile, the traffic will be concentrated on the shortest path, resulting in some nodes over the path dying faster than in other protocols. Furthermore, the occasional disconnections of the network made data delivery impossible. However, with CMMBCR, it tries to balance the power consumption evenly among nodes and is capable of avoiding this kind of network partition. This is only possible if we apply CMMBCR to the underlying DSR protocol to periodically acquire the best route. In other words, whenever the source node tries to find the path to the destination, CMMBCR can contribute to prolong the lifetime of each node. However, this is only applied when performing route recovery caused by the route breakage due to power outage or node movement. During the data transfer session, our protocol outperforms other protocols that do not have power-aware route maintenance, especially in terms of throughput over long time periods (Figure 4).

In addition, we also investigate how many nodes are put into the FVSZ state over time. As expected, the MTPR scheme without power-aware route maintenance has higher fraction of nodes in FVSZ state over a period of time since it does not consider the remaining power of nodes. This results in using up a node's battery, causing it to die early. Although CMMBCR can prolong the lifetime of nodes more or less, CMMBCR cannot always guarantee the longer lifetime of nodes since a new power-aware route can be obtained only through periodic searching. In contrast, our protocol shows the best performance in terms of lifetime of nodes (Figure 5).

However, our protocol has some disadvantage of generating more control packets because it floods the route recovery packets to acquire alternative paths more often than MTPR and CMMBCR without power-aware route maintenance feature (Figure 6). Furthermore, the reason why CMMBCR shows more number of control packets than MTPR is that CMMBCR utilizes more longer path than the MTPR protocol with the fixed transmission range. This results in more route recovery processes with the route failures caused by nodes' movements.

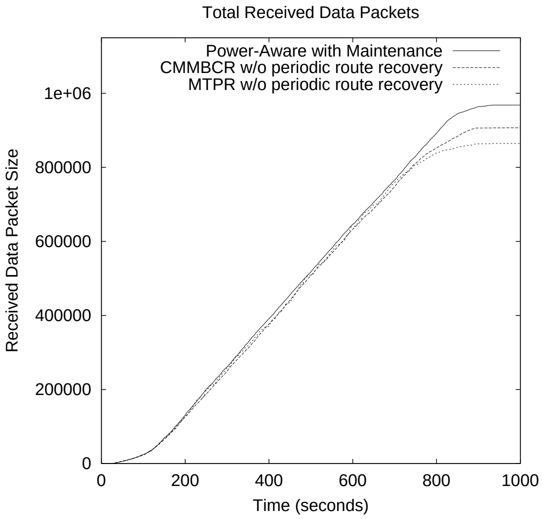

Fig. 4. Total number of data packets delivered.

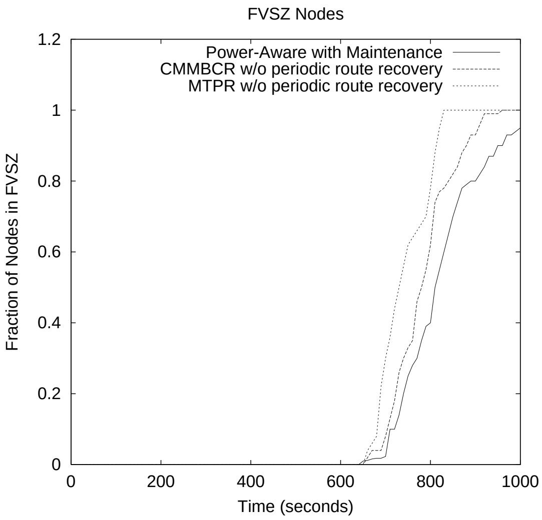

Fig. 5. Fraction of nodes in FVSZ state.

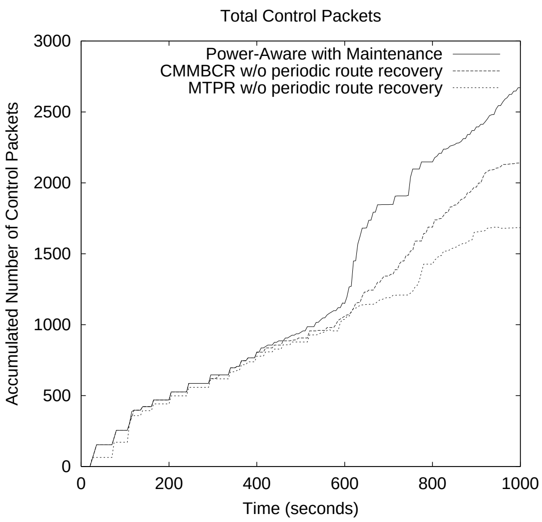

Fig. 6. Total number of control packets.

V. Conclusions

We introduced power-aware routing features for mobile ad hoc networks. Specifically, our features can be applied to on-demand reactive routing protocols without the need for periodic route recovery. The goal of our work was to distribute power consumption evenly among nodes participating in the network in order to extend the lifetime of the network. If there are many nodes that can no longer relay packets due to lack of power, the lifetime of the network will be shortened. Therefore, when acquiring routes, we adopted the CMMBCR protocol to both prolong the lifetime of nodes and to minimize the total transmission power per packet. In addition, we proposed an efficient algorithm that utilizes two power-level thresholds at nodes for selecting nodes that would be notified to re-route their connections. Through simulations, we observed that our protocol outperforms the MTPR and CMMBCR schemes when they are applied to current on-demand routing protocols without periodic route recovery.

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