PER: A Power-Life Extension Routing Protocol Using a Round Robin Scheme for Mobile Ad Hoc Networks

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Abstract—**A mobile ad hoc network (MANET) consists of mobile hosts which can peer-to-peer communicate with other mobile hosts through the multi-hopping routing. Each mobile device which operates the mobile computing and wireless communication operations is mainly depended on the battery. The power consumption of the battery is very important for supporting the wireless mobile applications. This problem is intensively investigated in wireless mobile ad hoc networks. In this paper, we propose a PER: Power-life Extension Routing protocol using a round robin scheme for wireless mobile ad hoc networks. Existing power-awareness routing protocols in MANETs mainly search for a power-awareness route with the consideration of the minimum total transmission power (MTPR protocol), or the minimum battery cost (MBCR protocol), the min-max battery cost (MMBCR protocol), and the minimum drain rate (MDR protocol). The key idea of our scheme is a simple multi-path routing between each possible pair of two three-hop neighboring nodes. This scheme identifies many disjoint sub-paths between one pair of three-hop neighboring nodes. A round robin scheme is applied on the multiple disjoint sub-paths such that the power consumption can be evenly distributed into all sub-paths, such that each sub-path is responsible for the less amount of power consumption. This scheme can promote and extend the power-awareness route lifetime. Finally, the simulation results demonstrate this improvement.**

Keywords— 3G, Channelization code, Personal Communication Service, code assignment, code reassignment, OVSF, wireless communication, WCDMA.

I. INTRODUCTION

Mobile ad hoc networks (MANETs) consist of wireless hosts that communicate with each other in the absence of a fixed infrastructure. Due to considerations such as radio power limitations, power consumption, and channel utilization, a mobile host may not be able to communicate directly with other hosts in a single-hop fashion. Most ad hoc networks today operate on battery, the power-consumption problem becomes an important issue. To maximize the lifetime of ad hoc networks, the power consumption rate of each node must be evenly distributed and the overall transmission power for each connection request must be minimized. To support the lightweight, compact, portable computing devices, the power consumption problem is the critical issue for almost all kinds of portable device, including MANET, bluetooth [2], and wireless sensor networks [11]. The battery power supports the life for all of the mobile devices. Battery power is a limited resource for portable devices. Without the power, any mobile device will become useless. The battery technology is not likely to progress as fast as the computing and communication technologies. Therefore, how to lengthen the lifetime of batteries is an important issue, especially for the MANETs.

Power-aware routing protocols have been proposed based on various power cost functions [1][5][6][7] [8][9][10]. Scott *et al.* [7] developed a Minimum Total Transmission Power Routing (MTPR) protocol to minimize the total transmission power consumption for the multi-hop communication. Since the transmission power is proportional to the transmission distance between two neighboring nodes, therefore MTPR protocol always selects a route with minimum total transmission power but with more hops, although the Dijkstra's shortest path algorithm was attempted to be used in MTPR protocol [7]. However, MTPR protocol suffers longer end-to-end delay from the greater number of hopes. Singh *et al.* [8] proposed the Min-Max Battery Cost Routing (MMBCR) protocol to determine a route with the consideration of the metric of residual battery power capacity. MMBCR protocol allows the nodes with high residual capacity to participate in the routing process more often than the nodes with low residual capacity. 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, there is no guarantee for MMBCR protocol that minimum total transmission power paths will be selected. Toh [10] devised a hybrid approach, namely the Conditional Max-Min Battery Capacity Routing (CMMBCR) protocol. CMMBCR protocol considers both the total transmission energy consumption of routes and the remaining power of nodes. When all nodes in some possible routes have sufficient remaining battery capacity, a route with minimum total transmission power among these routes is chosen. To maximize the lifetime of ad hoc mobile networks, the power consumption rate of each node must be evenly distributed. Specially, CMMBCR protocol is proposed in [10] to satisfy these two constraints simultaneously. Kim *et al.* [3] proposed the Minimum Drain Rate (MDR) mechanism, which incorporates the drain rate metric into the routing process. This mechanism is basically a power-aware route selection algorithm that could be applied to any MANET routing protocol when performing route discovery. MDR still does not guarantee that the total transmission power is minimized over a chosen route, as in MMBCR. However, based on a γ threshold, CMMBCR can apply MDR instead of MMBCR when all routes have nodes with low battery capacity in order to prolong the lifetime of both nodes and connections as well as to minimize the total transmission power consumed per packet.

In this paper, we propose a power-life extension scheme to both consider the MAC sub-layer and network layer to extend the power lifetime of a power-aware route. In this paper, we propose a PER: Power-life Extension Routing protocol using a round robin scheme for wireless mobile ad hoc networks. Existing power-awareness routing protocols in MANETs mainly search for a power-awareness route with the consideration of the minimum total transmission power (MTPR protocol), or the minimum battery cost (MBCR protocol), the min-max battery cost (MMBCR protocol), and the minimum drain rate (MDR protocol). The key idea of our scheme is a simple multi-path routing between each possible pair of three-hop neighboring nodes. This scheme identifies many disjoint sub-paths be-

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tween one pair of three-hop neighboring nodes. A round robin scheme is applied on the multiple disjoint sub-paths such that the power consumption can be evenly distributed into all sub-paths, such that each sub-path is responsible for the less amount of power consumption. This scheme can promote and extend the power-awareness route lifetime. Finally, simulation results demonstrate this improvement.

The rest of this paper is organized as follows. Section II presents related works. Section III presents our power-life extension routing protocol. Section IV discusses the simulation results to illustrate the performance achievement. Finally, Section V concludes this paper.

II. EXISTING PROTOCOL REVIEW

We review three kinds of important battery-awareness routing protocols [3][7][8][10] as follows.

1. MTPR (Minimum Total Transmission Power Routing) protocol [7] - MTPR protocol develops a route with the minimum total transmission power.

2. MMBCR (Min-Max Battery Cost Routing) protocol [8] and CMMBCR (Conditional Max-Min Battery Capacity Routing) protocol [10] - MMBCR mainly develops a battery cost routing scheme to search for a route with the maximum power lifetime. In addition, CMMBCR protocol adopts the MMBCR approach to find out many possible routes, and then applied MTPR protocol to try to determine a route with the minimum total transmission cost among these routes.

3. MDR (Minimum Drain Rate) protocol [3] - MDR protocol constructs a route by mainly considering the minimum drain rate.

Many existing routing protocol may fail to work in their route discovery process unless all hosts are awaken at the time of the searching process. This work is mainly focus on how to extend the power-life of a searching route. Therefore, we assume that all hosts are awaken at the time of the searching process. For each a beacon interval, three kinds of power states are defined here to be used to measure the power consumption of a multi-hop routing. First power state is that both of the ATIM window and the data transmission interval are active mode. Second power state is that the ATIM window is active mode and the data transmission interval is PS mode. The third power state is that both of the ATIM window and the data transmission interval are PS mode. In this paper, a short-path-based route is identified if the route has the maximum number of intermediate nodes with the third power state. To illustrate our main idea, we use an example to explain the power-life extension scheme as follows. If a route (S, A, B, D) is constructed as shown in Fig. 1(a). As illustrated in Fig. 1(b), after node S sending a data packet, it waits for two beacon intervals. On receiving a data packet from S for node A, node A forwards the data packet to B, and then waits for one beacon interval. On the next beacon interval, node B receives a data packet from A and forward the data packet to D, and then waits for one beacon interval. Destination D waits for two beacon intervals and then receives the data packet from node B. For all of the intermediate nodes of a route (except for the source and destination nodes) has two active beacon intervals and one PS beacon interval for three adjacent beacon intervals.

On the contrary, a route $(S \begin{bmatrix} A \\ B \end{bmatrix} D)$ is shown in Fig. 2(a), data packet is sent from source node S through A to destination D, and the next data packet is send from source node S through B to destination D. For a possible route, $(\alpha \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \vdots \\ \gamma_\kappa \end{bmatrix} \beta)$, in general, each intermediate nodes in $\begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \vdots \\ \gamma_\kappa \end{bmatrix}$ has two active beacon intervals and four PS beacon intervals. An example is demonstrated in Fig. 2(b). This implies that our proposed protocol can be adopted to be extending the power-life of a route.

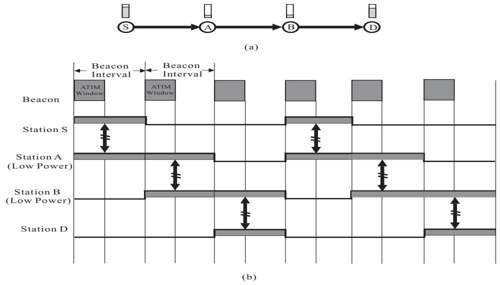


Fig. 1. The status of using active and PS modes in the traditional uni-path routing

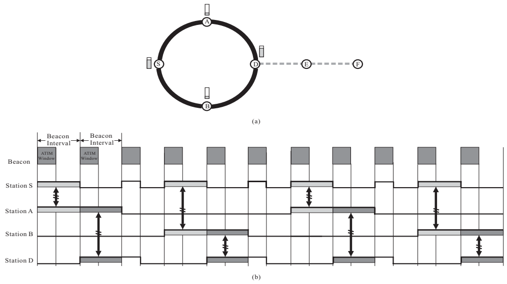


Fig. 2. The status of using active and PS modes in the PER routing

III. THE PER (POWER-LIFE EXTENSION ROUTING) PROTOCOL

A. Route discovery phase:

Step 1. Source initiates and floods a route request packet ROUTE_REQUEST(*grandfather_node* = $\emptyset$, *father_node* = $\emptyset$, Min, *grandfather_power* = $\emptyset$) into a MANET. Let *grandfather_node* and *father_node* denote as grandfather and father nodes of the current node (source node), *grandfather_power* denote as grandfather node's residual power and $Min = \frac{RBP_{source}}{DR_{source}}$, where RBP_{source} is the residual battery power at source node, and DR_{source} is the battery power drain rate for the source node.

Step 2. If a node α received the packet from source, then let ROUTE_REQUEST(*grandfather_node* = $\emptyset$, *father_node* = source node, Min, *grandfather_power* = $\emptyset$), where Min =min(Min, $\frac{RBP_\alpha}{DR_\alpha}$) and then floods the ROUTE_REQUEST packet into the MANET.

Step 3. If a node β received a ROUTE_REQUEST packet from node α, let old *father_node* be equal to *father_node* and Min_{old} be equal to Min in the receiving ROUTE_REQUEST packet. Let ROUTE_REQUEST(*grandfather_node* = old *father_node, father_node* = α, Min, *grandfather_power* = old *father's power*), where Min =min(Min_{old}, $\frac{RBP_\beta}{DR_\beta}$) and then to flood the packet.

Step 4. If a node β received κ ROUTE_REQUEST packets with the same *grandfather_node* but with the different

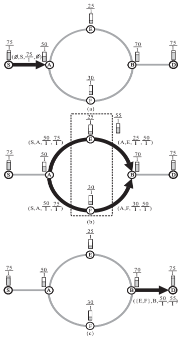


Fig. 3. A PER route discovery phase

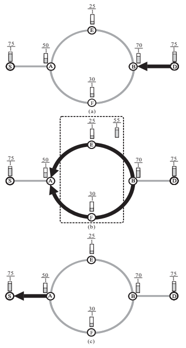


Fig. 4. A PER route reply phase

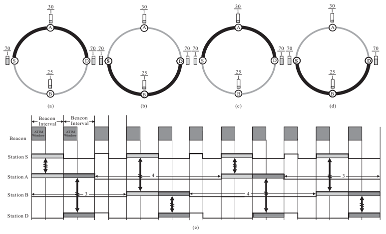


Fig. 5. Example of round robin scheme

father_node, assumes let $\{\alpha_1, \alpha_2, \cdots, \alpha_\kappa\}$ be a set of all different *father_nodes* and let $Min_1, Min_2, \cdots, Min_\kappa$ sequentially be the Min field from κ ROUTE_REQUEST packets. All κ receiving ROUTE_REQUEST packets are formed into a new ROUTE_REQUEST(*grandfather_node*= $\{\alpha_1, \alpha_2, \cdots, \alpha_\kappa\}$, *father_node* $= \beta$, $Min = \min(\sum_{1\leq i\leq\kappa} Min_i, \frac{RBP_\beta}{DR_\beta}, grandfather\_power))$ and continue to flood the new ROUTE_REQUEST packet into the MANET. Observe that the use of *grandfather_power* is to avoid the condition of $\sum_{1\leq i\leq\kappa} Min_i > grandfather\_power$.

For example as shown in Fig. 3, the route discovery phase discovers a route $(S, A, \begin{bmatrix} E \\ F \end{bmatrix}, D)$, and destination node D receives a ROUTE_REQUEST($\{E, F\}, B, \frac{50}{1}, \frac{55}{1}$) packet. Observe that if using MDR protocol, destination node receives ROUTE_REQUEST($E, B, \frac{25}{1}$) and ROUTE_REQUEST($F, B, \frac{30}{1}$) packets. This indicates that the minimum power consumption ratio of routes (S, A, E, B, D) and (S, A, F, B, D) are $\frac{25}{1}$ and $\frac{30}{1}$. Therefore, the power-life route of (S, A, E, B, D) and (S, A, F, B, D) will be smaller than our identified route $(S, A, \begin{bmatrix} E \\ F \end{bmatrix}, D)$ with the minimum power consumption ratio $\frac{50}{1}$.

B. Route reply phase:

Step 1. Destination receives κ ROUTE_REQUEST packets, each one is a route from source node to destination node. Each route $P_j, 1 \leq j \leq \kappa$, has its own Min_j from its ROUTE_REQUEST packet. Destination selects a route with maximum value for all Min_j, $1 \leq j \leq k$, i.e., $\underset{1\leq j\leq k}{Max} Min_j$. Assume that a route $(S, \cdots, \alpha, \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \vdots \\ \gamma_\kappa \end{bmatrix}, \beta, \cdots, D)$, where $\begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \vdots \\ \gamma_\kappa \end{bmatrix}$ is one of supernodes in the selected route.

Step 2. Destination replies a packet from destination node to source node to confirm the selected route according to the reversed path of $(D, \cdots, \beta, \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \vdots \\ \gamma_\kappa \end{bmatrix}, \alpha, \cdots, S)$. If the packet arrives at node α, then node α must keeps the supernode information of $\begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \vdots \\ \gamma_\kappa \end{bmatrix}$ in routing table of node α.

For example as shown in Fig. 4, destination determines a route $(S, A, \begin{bmatrix} E \\ F \end{bmatrix}, D)$ and replies a confirmed packet according to the path $(D, \begin{bmatrix} E \\ F \end{bmatrix}, A, D)$. During the route reply phase, it keeps the supernode information $(A, \begin{bmatrix} E \\ F \end{bmatrix}, D)$ in the routing table of node A. This supernode information will be useful in the round robin phase.

C. Round robin phase in power-saving (PS) mode:

For a $(\alpha, \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \vdots \\ \gamma_\kappa \end{bmatrix}_i, \beta)$, the round robin scheme for power-saving is presented. The basic idea of the round robin scheme is that each one of $\gamma_1, \gamma_2, \cdots$, and γ_κ takes turn to act as an intermediate node between nodes α and β. This task is accomplished by enlarging the number of PS beacon intervals. To avoid the transmission collision problem, each node of $\gamma_1, \gamma_2, \cdots$, and γ_κ must initially wait for a different backoff time. The details is given.

Step 1. All of $\frac{RBP_{\gamma_1}}{DR_{\gamma_1}}, \frac{RBP_{\gamma_2}}{DR_{\gamma_2}}, \cdots$, and $\frac{RBP_{\gamma_\kappa}}{DR_{\gamma_\kappa}}$ for nodes $\gamma_1, \gamma_2, \cdots$, and γ_κ are sorted into a sorted sequence. Without loss of generality, we assume that $\frac{RBP_{\gamma_1}}{DR_{\gamma_1}} \geq \frac{RBP_{\gamma_2}}{DR_{\gamma_2}} \geq \cdots \geq \frac{RBP_{\gamma_\kappa}}{DR_{\gamma_\kappa}}$ herein.

Step 2. Initially, node γ_1 waits for zero beacon interval (backoff time), and other node γ_j, $2 \leq j \leq \kappa$ waits for $3 \times (j-1)$ beacon intervals (backoff time). This backoff time is used to avoid the transmission collision problem.

Step 3. The active beacon interval for all nodes $\gamma_1, \gamma_2, \cdots$, or γ_κ is two; one is used to receiving packet from its father node and another one is used to forwarding the just-in-time received packet to its child node.

Step 4. The number of power-saving (PS) beacon intervals for each node is $1 + 3 \times (\kappa - 1)$.

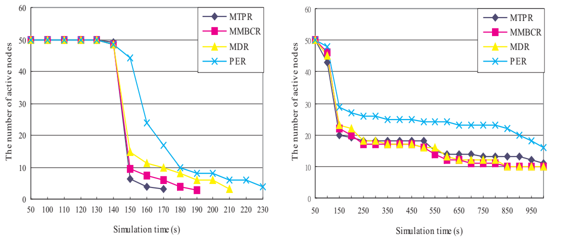
For instance, the sorted result is $\frac{30}{1} > \frac{25}{1}$ for supernode $\begin{bmatrix} A \\ B \end{bmatrix}$ as shown in Fig. 5(a). Consider a $(S, \begin{bmatrix} A \\ B \end{bmatrix}, D)$, node A does not wait for any backoff time at first and begin with two active beacon intervals. Node B initially waits for 3 beacon intervals. After it, both of nodes A and B periodically and sequentially maintain two active intervals and four PS beacon intervals as illustrated in Fig. 5(e).

IV. PERFORMANCE EVALUATION

To investigate the performance achievement, we compare our PER protocol with MTPR, MMBCR and MDR protocols using the ns-2 simulator (version 2.1b9a) [4] with the CMU wireless extension. The DSR protocol developed in ns-2 is used as the underlying route discovery and maintenance protocol. During the route discovery and reply phases, the destination node tried to determine a power-saving route with considering various power-aware selection mechanisms, after collecting all the possible routes from the source nodes. We use the "random waypoint" model to generate each node's movement. In this model, the motion is characterized by two factors; (a) *maximum speed* and (b) *pause time*. We assumed all mobile nodes to be equipped with IEEE 802.11 network interface card. To simulate the real scenario, we adopt the power consumption model of Lucent ORiNOCO WLAN PC Card, where transmitting, receiving and idling power consumption are 1.4, 0.9, and 0.05 watts/s, respectively. In our simulation, all nodes initially have the same power. The simulation parameters are given below.

- The packet length is 512 bytes.
- The transmission radius is 250 meters.
- The number of mobile hosts is 50.
- Each simulated result is obtained through 1000 runs.
- The data rate is 2 Mbit/s.
- The maximum speed of each mobile node is 10.0 m/s.

We mainly investigate the network lifetime by considering different routing protocols, including MTPR, MMBCR, MDR, and PER routing schemes. The network lifetime directly affects the system throughput. The performance metrics consist of the number of active nodes. A node is called as *active node*, which has enough residual power to be sending, delivering, and receiving data. The simulated MANET network is distributed over 500m×500m and 1000m×1000m areas to indicates that the dense and spare networks, respectively. The simulation results of performance of the number of active nodes are shown in Fig. 6 and to reflect the status of network lifetime in dense and sparse networks. Fig. 6(a) shows that our PER protocol can offer the greater number of active nodes even if the simulation time is large in the dense network. Further, all of routing protocols, including MTPR, MMBCR, MDR and PER, are compared in the sparse network as shown in Fig. 6(b). In average, the number of active nodes of PER protocol is more than other protocols in the sparse network. This strongly implies that our scheme can actually extend the power lifetime by adopting PER protocol.



(a) (b)

Fig. 6. Performance of the number of active nodes in (a) dense and (b) sparse networks

V. CONCLUSION

In this paper, we propose a PER: Power-life Extension Routing protocol using a round robin scheme for wireless mobile ad hoc networks. This paper mainly develops a power-life extension scheme such that existing power-awareness routing protocols can be adopted our presented scheme to extend the route lifetime. The simulation results demonstrate this improvement.

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