p-MANET: Efficient Power Saving Protocol for Multi-Hop Mobile Ad Hoc Networks

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Abstract

In this paper, we propose an efficient power saving protocol for multi-hop mobile ad hoc networks, called p-MANET. Our design is expected as a new foundation MAC layer power saving protocol. The main goals of p-MANET protocol are to reduce significant power consumption and transmission latency, and to achieve efficient power saving. Each mobile node in p-MANET only needs to become active during one beacon interval for every n interval, where n is the size of a super frame. Thus, efficient power saving is expected. p-MANET also yields low transmission latency because that every mobile node is aware of the active beacon intervals of its neighbors such that it can easily choose a neighbor in active mode or with the least remaining time to wake up to forward packets. Simulations are also conducted to show the efficiency of the proposed p-MANET.

1. Introduction

With recent performance advancement in wireless technology, portable computing platforms and small wireless devices become indispensable devices of our daily life. The use of a portable device is constrained by its energy, making power conservation the most critical issue for portable devices and their applications. In this paper, we address the energy efficient issue to optimize the use of the battery longevity.

There has been a lot of researches emphasis on energy efficient protocols [1-4][6-7] for mobile ad hoc network (MANET). The most well known power saving strategy is the IEEE 802.11 Power Saving Mode (PSM) [1]. But it is originally designed for the single hop environment, making it inapplicable to MANET in which multi-hop connectivity is the most prominent feature. Tseng and Hsu [2] presented a Quorum-based protocol, which supports low-power sleep mode to operate across multiple hops. The protocol is able to guarantee that a PS node always has at least two entire beacon windows that are fully covered by another PS node's active windows in every n2 beacon intervals. The efficiency of power saving of the above approach is less sensitive to the number of nodes because that it uses beacons, not flooding, to find neighbor nodes. However, this also makes flooding-based routing protocol inapplicable to this kind of approach. The proposed approach [5] can provide path activation, delay minimization, and energy conservation. However, the proposed strategies require additional support from the MAC layer. S-MAC [7] applies message passing to reduce energy consumption when listening to an idle channel. But S-MAC is specially designed for sensor networks; therefore it is not directly applicable to MANET since the maintenance overhead will be too high. SPAN [3] and GAF [11] reduce energy consumption and delay latency conspicuously in densely networks. The mobile nodes along the routing backbone, denoted as coordinators, will stay in active mode to preserve connectivity. Other nodes may stay in sleep mode until receiving packets. However, a coordinator has to stay in active mode to maintain the routing backbone which will cause great power consumption.

In this paper, we propose an efficient power saving protocol, called p-MANET, for multi-hop MANET. Our design is expected as a new fundamental MAC layer power saving protocol for MANET. Following mechanisms in p-MANET are proposed to reduce power consumption as well as transmission latency, namely efficient power saving mechanism, and low latency next hop selection mechanism. The efficient power saving mechanism, proposed for the MAC layer,

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reduces power consumption on useless tasks, such as idle listening, collision, overhearing, and control overhead. Specifically, there are two power management modes in p-MANET: listen and power-saving (PS) mode. Under the listen mode, a mobile node awakes and may receive data. Under the power-saving mode, a mobile node sleeps in most of time except for transiting data to neighbor nodes and sending beacon messages periodically. Each mobile node in p-MANET only needs to be in listen mode during one beacon interval for every n intervals, where n is the number of beacon intervals within a cycle (referred to as super frame). One of the most important features of p-MANET is that each mobile node uses a global hash function and its MAC address to determine when to enter the listen mode. So, a sender can use the global hash function to determine the listen interval of the destination and send the packets efficiently. A beacon inhibition mechanism is also proposed in p-MANET to prevent the broadcast storm. Finally, the low latency next hop selection mechanism adopts heuristic strategies to efficiently select the next hop neighbor node for transmitting a packet. For example, an appropriate next hop candidate would be a neighbor with least remaining time to wake up or a neighbor that is awake in listen mode.

Performance of p-MANET is evaluated in terms of fraction of survived node and neighbor discovery time via simulations. Our simulation results show that, compared with the Quorum-based protocol [2], about 10% to 70% energy savings can be achieved by our p-MANET under different scenarios. The improvement of survival time of p-MANET over that of the Quorum-based protocol ranges from 8.3% to 71%. Simulation results also shows that the neighbor discovery time of p-MANET is also significantly reduced.

The rest of the paper is organized as follows: The main design principles of the p-MANET are given in Section 2. Performance evaluation results are shown in Section 3. Finally, Section 4 follows with a concluding remark.

2. Overview of the p-MANET Protocol

In this section, we describe an efficient power saving protocol, include efficient power saving mechanism and low latency next hop selection mechanism, for multi-hop MANET, called p-MANET. The efficient power saving mechanism avoids power consumption on unnecessary tasks, such as idle listening, collision, overhearing, and control overhead. The low latency next hop selection mechanism provides heuristic strategies to efficiently select next hop neighbor node on packet forwarding.

2.1. System Model

In this subsection, we describe the system model of p-MANET. We assume a super frame consists of n beacon intervals, as shown in Figure 1. In addition, p-MANET is a periodically awake interval protocol, which assumes that beacon intervals of mobile nodes can be synchronized by global synchronization algorithm [13]. For ease of explanation, each beacon interval in a super frame is associated with a unique color. For example, there are 3 colored intervals in Figure 1, namely, Red (R), Green (G), and Blue (B) intervals. Each mobile node will enter the listen mode, only at one beacon interval during a super frame and will stay in PS mode during the rest of intervals. Each mobile node uses its MAC address as the input to a pre-chosen hash function, such as SHA-1 [10], to determine which beacon interval within a super frame it needs to enter the listen mode. With global synchronization, each mobile node easy knows the listen mode of its neighbors. Each beacon interval consists of three windows: Beacon Window (BW), Multi-hop Traffic Indication Map (MTIM) Window, and Data Window (DW). A mobile node needs to send beacon packet periodically to remedy drift time with neighbor nodes at each beacon window, no matter it is in listen mode or PS mode. The MTIM frame [2] serves the similar purpose as Announcement Traffic Indication Map (ATIM) frame in IEEE 802.11. Packets will be actually transmitted during the data window. A mobile node will be active during MTIM and data window if it is in listen mode, or it is in PS mode but has packets to transmit.

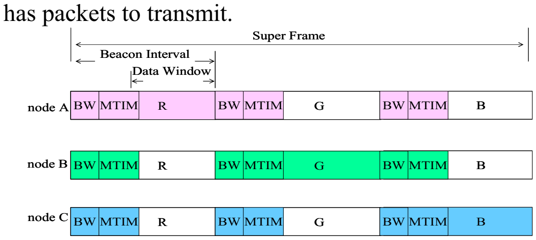

Figure 1. A super frame consists of several colored beacon intervals

2.2. Efficient Power Saving Mechanism

The efficient power saving mechanism relies on the aforementioned super frame structure and the use of hash function for a mobile node to determine which beacon interval to enter listen mode. As a consequence, a mobile node can avoid unnecessary listening and

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save time and energy on sending and receiving date. Recall that a mobile node in listen mode will always awake and listen to the channel or transmit packets[1]. A mobile node in PS mode will be awake in BW to send a beacon. If the mobile node has packet to send, it will be awake in the appropriate MTIM window to send a MTIM frame to the destination and transmit the packet in the following DW. How to know which MTIM window to send the MTIM frame is also based on the hash function and is described in detail as follows.

Recall that all mobile nodes share the same hash function and all next hop nodes in the routing table of a mobile node are neighbors of the node. Therefore, when a mobile node wants to transmit a packet, it first looks up the next hop node from the routing table. Since the next hop is the mobile node's neighbor, it will also know the MAC address of the next hop. It then uses the hash function to get the beacon interval that the next hop will enter the listen mode, say it is the ith interval of the super frame. The mobile node will then send the MTIM frame and the packet in the MTIM window and DW window of the ith interval, respectively. Since the corresponding next hop will enter the listen mode at the ith interval, it will be able to listen to the MTIM frame and receive the packet in the DW window.

Figure 2 illustrates the example of how a mobile node communicates with a neighbor node. Node A, B, C will enter the listen mode at beacon interval a, a, and b, respectively. If node B wants to transmit a data frame to node C, it first calculates the interval that node C will enter the listen mode by the hash table. During the MTIM window of the beacon interval b, node B sends the MTIM frame to notice node C that a data frame will be sent to it. Upon receiving the MTIM frame, node C replies an ACK to node B. Since node A does not have any packets to send, it enters the sleep mode after BW window of interval b. Node B will enter the sleep mode after sending the packet while node C can also enter the sleep mode if all data, notified in the MTIM window, have been received.

With the hash function, p-MANET is much more efficient than the solution proposed in [4] where each mobile node needs to run a schedule bookkeeping protocol to keep track of neighbor schedules. Since a mobile node only enters the listen mode once every n intervals, the p-MANET protocol obviously is more efficient when n is large.

Next, we discuss how to avoid collision and overhearing in p-MANET. The MAC layer of IEEE 802.11 uses a contention based scheme, namely, CSMA/CA, to solve the collision problem. Our protocol follows similar collision avoidance mechanism of 802.11 which consists of both virtual and physical carrier sense and the RTS/CTS handshaking mechanism. In p-MANET, beacon messages are sent without RTC/CTS handshaking while MTIM frame and data frame are sent by following the sequence four operations, RTS/CTS/DATA/ACK, between the sender and receiver. Moreover, a general idea of network allocation vector (NAV) of IEEE 802.11 are adopted and extended in p-MANET to avoid collision as well as save power. The NAV of IEEE 802.11 indicates the remaining time of an on-going data transmission. The channel is considered to be busy if the NAV value is not zero. Based on the NAV, a mobile node in p-MANET can either stop sensing the media or entering the sleep mode to save power if it is not the corresponding sender or receiver.

Figures 3 and 4 illustrate an example of how a p-MANET mobile node utilizes the NAV. Consider the case that, in Figure 3, A and B want to send data packets to node C at the same time. In addition, node A, B, and E enter the listen mode at G interval while node C and D enter the listen mode at R interval. Node A and B send the MTIM frame to node C during the MTIM window of G interval. Assume node C first receives the MTIM frame from node A. Node C can schedule node A to send data frame during slot 1 to slot 4 of the DW window of G interval and include this scheduling information in the ACK of MTIM frame to node A. Later on, node C receives the MTIM frame from node B and schedule node B to send data frame

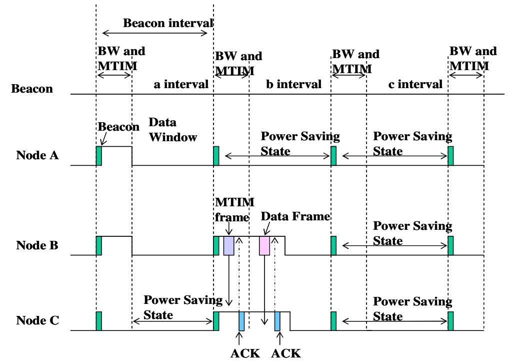

Figure 2. The example of a mobile node how to communicate with a neighbor node

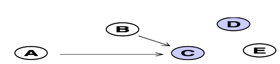

Figure 3. Topology for the example of use of NAV

[1] It could enter PS mode during the data window if it has no more data to receive.

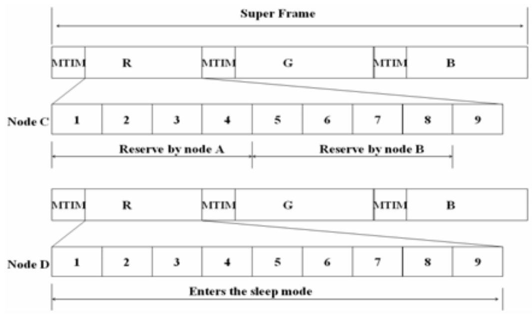

Figure 4. Scheduling of mobile node C and D in the example of use of NAV

during slot 5 to slot 8. Similarly, node B will receive this scheduling information in the ACK from node C. During the DW window, since there could be other sender/receiver pair that also scheduled for transmission, node A and B still need to use RTS/CTS to seize the channel before transmission. However, node B can enter the sleep mode for the first four slots since node A is scheduled for transmission first. On the other hand, node A can enter the sleep mode after transmission. Other nodes can use the NAV of RTS/CTS to estimate how long to sleep before wake up to contend for the channel again. Node D can enter sleep mode if it does not have data to receive. .

As aforementioned, each mobile node needs to periodically broadcast a beacon message to its neighbors for neighbor discovery. In a densely distributed MANET, too many mobile nodes try to send beacon messages at the same time will cause the beacon storm problem. In the following, we depict a beacon inhibition mechanism to solve this problem. The basic idea is to have a mobile node to send out a beacon message only if the total number of beacon messages received in current BW is less than a threshold. The threshold can be estimated based on the length of BW and the time to send a beacon. For example, if the BW is 4 ms and it requires 0.5 ms to send a beacon, then the threshold should be less than 8. Therefore, with the beacon inhibition mechanism, a mobile node will count the number of beacon messages received so far and depress its beacon sending procedure if the number exceeds the pre-defined threshold. Figure 5 shows that the flowchart of the beacon inhibition mechanism.

2.3. Low Latency Next Hop Selection Mechanism

Our p-MANET is a foundational MAC protocol in MANET, but can provide the routing metric for routing protocols choosing a more efficient next hop. However, lower routing latency can be achieved if the underlying routing protocol can take the power management strategy of p-MANET into consideration. In the following, we propose a neighbor selection strategy for distance-vector based (table-driven) routing protocols and on-demand routing protocols.

The table-driven protocols, such as DSDV [8], maintain a routing table in which each entry consists of destination and next hop information. A quite common phenomenon is that to a particular destination, two or more neighbor nodes are equally good for forwarding. In general, the routing protocol will randomly select one as the next hop to that destination. However, for p-MANET, one should select the neighbor node that will enter the listen mode as close to that of the mobile node under consideration as possible, but not earlier to reduce the relay latency. For example, consider the p-MANET in Figure 6. For simplicity, assume that the super frame only consists of two beacon intervals: W (white) and G (gray). Nodes S, A, C will enter the listen mode in G interval and the other nodes will enter the listen mode in W interval. For node S, a packet to node D can be either relayed by node A or node E. Clearly, with the low latency next hop selection mechanism, node A is preferred by node S as they enter the listen mode in the same interval. Therefore, the packet can be forwarded in one beacon interval. If node E is chosen as the next hop, then relaying the packet would require at least two beacon intervals. If the neighbor selection mechanism is performed at each mobile node, the end-to-end delay of sending a packet should be reduced. To support this mechanism only needs the existing routing protocols and hash function.

The low latency next hop selection mechanism is not directly applicable to on-demand routing protocols, such as DSR [9]. With on-demand routing, the source node specifies the intermediate nodes of a route that a packet should traverse to reach the final destination. The low latency next hop selection mechanism can be applied when the source node or an intermediate node forwards the route request (RREQ) during the route discovery phase.

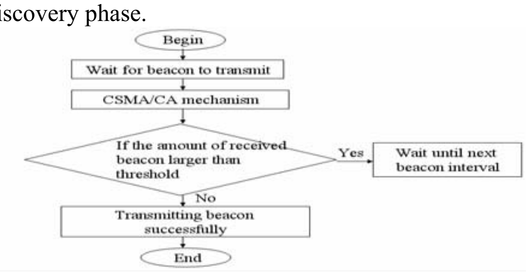

Figure 5. The flowchart of the beacon inhibition mechanism

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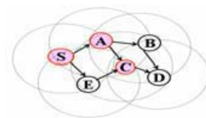


Figure 6. Example of low latency next hop selection mechanism

3. Performance Evaluation

In this section we compare the performance of the p-MANET with that of Quorum-based protocol [2] from two different aspects: fraction of survived node and neighbor discovery time. Our simulation models a network of 50 ~ 150 mobile nodes placed randomly within a 1000m x 1000m area. The power capacity, radio propagation range and channel capacity for each node is 100 Joule, 250 meters, and 2 Mbits/sec. The power model shown in Table 1 is adopted in our simulation, where L, the packet length, is set to 1024 bytes. The Random Way Point model [14] is adopted as our mobility model in which the pause time is set to 20 seconds. Mobility speed varies from 0 m/s to 20 m/s and, unless otherwise specified, the default mobility speed is set to 5 m/s. Multiple runs, each runs for 600 simulation times, are conducted for each scenario.

Table 1. Power consumption parameters used in simulations

Transmit	Receive	Idle	Sleep
454 + 1.9×L μJ/packet	356+0.5×L μJ/packet	843 μJ/ms	27μJ/ms

3.1. Fraction of survived node

The fraction of survived node is defined as the number of surviving nodes over the total number of nodes. The fraction of survived node, a commonly used performance metric, is a very important metric for evaluating a power-saving protocol [2][11-12]. Fraction of survived node is evaluated under several scenarios. In following simulations, the BW, the MTIM window, and the DW are set to 4ms, 16ms, and (beacon interval length - 20ms), respectively.

From simulation result, it shows that impact of various beacon interval lengths on the fraction of survived node. Obviously, the lifetime of the MANET prolongs as the length of beacon intervals increases. Because the beacon interval length increases, the number of beacon needs to send decreases. However, longer interval length also causes longer neighbor discovery delay which will be discussed later.

Figure 8 shows the impact of the size of super frames on the fraction of survived node with 100 nodes. In the Figure 8, Q(5) presented the results of the Quorum-based protocol with 5 × 5 matrix. We can observe that the p-MANET achieves considerably higher fraction of survived node than the Quorum-based protocol. The network lifetime of p-MANET is longer than that of the Quorum-based protocol by 6%, 38%, 60%, and 70% when the size of the super frame is 3, 5, 7, and 9, respectively.

We also evaluate the impact of node density and mobility speed on fraction of survived node. From Figure 9(a), we can observe that node density affects the performance of the Quorum-based protocol more significantly than that of p-MANET. The simulation results indicate that the scalability and energy conservation of p-MANET are better than that of the Quorum-based protocol under various node densities. Form Figure 9(b), node mobility will decrease the fraction of survived node as mobility incurs high power consumption on retransmission. The simulation results indicate that mobility speed has little impact on both protocols.

3.2. Neighbor Discovery Time

The neighbor discovery time is defined as the average time to discover a new joined node. Figure 10 shows that the neighbor discovery time increases almost linearly as the beacon interval length increases. Obviously, p-MANET significantly outperforms the Quorum-based protocol. We also can observe that there is a tradeoff between the neighbor discovery time and the network lifetime of the MANET. For high dynamic MANET with heavy traffic load, the beacon interval length should be set shorter to have more accurate neighbor information and, thus, better performance on routing. Contrarily, long beacon interval length should be preferred for stable MANET. We also evaluate the impact of the super frame size on the neighbor discovery time. Again, since a mobile node has less chance to enter the listen mode, the neighbor discovery time increases as the super frame size increases. In summary, the proposed p-MANET does not suffer from long neighbor discovery time problem.

4. Conclusion and Future Works

To prolong the battery life, power conservation is a very important issue for portable devices. In this paper, we propose an efficient power saving protocol, especially for multi-hop MANET, called p-MANET. p-MANET consists of two mechanisms. First, the efficient power saving mechanism avoids power consumption on unnecessary tasks. Next, the low latency next hop selection mechanism provides heuristic strategies to efficiently select next hop neighbor node on packet forwarding. Simulation results also show that p-MANET has higher fraction of survived node and lower neighbor discovery time than Quorum-based protocol.

Several issues of the p-MANET require further study. For example, we are designing a global synchronization mechanism. More evaluations will be done with more number of nodes and system complexity. We will also take the power consumption and message overhead into account and expect to have a more scalable routing protocol for large scale MANET.

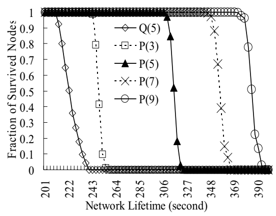
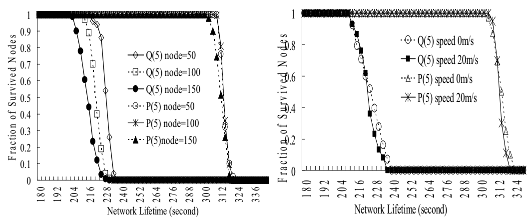


Figure 8. Hash spaces vs. fraction of survived node



(a) Node density **(b) Mobility**

Figure 9. Fraction of survived node

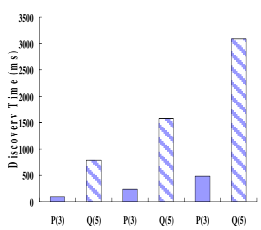


Figure 10. Neighbor discovery time

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