

# Energy Control based Routing for Mobile Ad hoc Network

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**Abstract**—Mobile Ad hoc network can operate in a self-organized and do not have any predefined infrastructure. However, the problem of limit energy often affects the communication in such network. In this paper, we present an energy management model which can effectively reduce energy consumption. Mobile nodes in such model transfer between power-save mode and active mode triggered by communication events and keep-alive timer. Base on the energy management model, we propose a new routing protocol with joint function considering both transmission power and residual energy of mobile nodes. Simulation experiments show that the proposed routing protocol with energy control mode can achieve higher performance and extend the life-span of network.

**Index Terms**—energy control, routing protocol, mobile Ad hoc network

## I. INTRODUCTION

The wireless host in mobile Ad hoc network (MANET) can communicate with each other through direct links or multi-hop routing. It has been used in a wide range of applications ranging from a battlefield to the user's living room. However, due to the limit battery energy of mobile nodes, how to prolong the lifetime of nodes as well as network becomes the key challenge in MANET, and it has received more and more attentions.

Most energy conservation methods in MANET are focus on transmission power control and dynamic turning off active nodes in network. Controlling the transmission power allows to significantly reduce the energy consumption for data sending and increase lifetime of the network. Cartigny proposes a local protocol based on energy management where each node requires only the knowledge of its distances to all neighbor nodes and distances between its neighbor nodes [1]. Nodes adjust their transmission power so as to achieve the minimum energy consumption according the local information. Ramanathan and ElBatt implement adjusting transmission power levels to achieve a desired degree of connectivity in the network, while using the minimum transmit power for delivering packets [2][3]. Bergamo etc. proposes a routing algorithm based on distributed power control, which can provide substantial transmit energy savings while introducing limited degradation in terms of throughput and delay [4]. The idea of distributed power control can be used as a means to improve the energy efficiency of routing algorithms in MANET. Each node in the network estimates the power necessary to reach its own neighbors, and this power estimate is used both for

tuning the transmit power and as the link cost for minimum energy routing. Simulations show that it can effectively save energy. However, if the transmission power accounts only for a small percentage of the overall power consumed, reducing the transmission power may not significantly impact the device's operational lifetime [5]. The scheme of dynamic turning off network interface will be used in MANET [6][7]. When the mobile nodes have no data to transceiver, they are transfer to sleep mode for saving energy [8][9]. Zhang proposes a unicast routing algorithm based on energy conservation with high robustness while bring with too much delay [10]. Godfrey proposes a simple algorithm based on random sleep, which needs not to maintain time synchronization [11]. But it is not supported by the routing layer. To solve the problem, Hu proposes an energy efficient algorithm combination with both routing and topology management [12]. It can provide better service performance and energy conservation.

In this paper, we deal with energy control over several layers in MANET. At low-level layer, we can trigger nodes to transfer between power-save mode and active mode. While at network layer, a routing protocol is proposed with new defined joint function, which can realize hop-by-hop and end-to-end energy control. The simulation results show that our energy conservation solution can effectively extend the life time of network and has high performance. It can provide an effect solution for wireless communication.

## II. ENERGY CONTROL MODEL

In this section, we propose an energy management model which considers all possible radio operation modes. In such model, each mobile node can be in one of two modes, i.e., active mode (AM) and power-save mode (PS). In active mode, a node is awake and may receive data at any time. In power-save mode, a node is sleeping most of the time and wakes up periodically to check for pending messages. Transitions between power-save and active mode are triggered by packet arrivals and expiration of the keep-alive timer.

Sub-state transitions inside power-save or active mode are controlled by the IEEE 802.11 MAC protocol. In such protocol, time is divided into beacon intervals for energy saving. At the beginning of each beacon interval, there exists a specific time interval, called the Ad-hoc traffic indication message (hereafter referred as ATIM) window, where every node is awake. When a node has a packet to transmit, it first transmits an ATIM frame to the

destination node during the ATIM window. When the destination node receives the ATIM frame, it replies with an ATIM ACK. After the ATIM and ATIM ACK handshake, both the source and the destination will stay awake for the remaining beacon interval to perform the data transmission. A node that has not transmitted or received an ATIM frame during the ATIM window may enter the sleep state after finishing its ATIM window.

Since the performance of energy saving is significantly affected by the size of the ATIM window, Jung and Vaidya propose the idea of NPSM (i.e., New Power Saving Mechanism) and removes the ATIM window in order to reduce control overhead in [14]. Using such mechanism, time is still divided into beacon intervals. At the start of a beacon interval, every node enters an awaked state for a specified duration called DATA window. The DATA window can be considered analogous to the ATIM window as mentioned above since every node is awake during the DATA window. However, nodes transmit data packets during the DATA window without any ATIM or ATIM ACK transmission. NPSM has a different way to announce pending packets to destination nodes.

While a path in the network is going to be used, the nodes along that path should be awake quickly so as to avoid unnecessary delay for data transmission. On the contrary, the nodes should be allowed to sleep for energy saving. Since many control messages are flooded throughout the network and provide poor hints for the routing of data transmissions, they will not trigger a node to stay in active mode. However, data transmissions are usually bound to a path on relatively large time scales and they are a good hint for guiding energy management decisions. For data packets, the keep-alive timer should be set on the order of the packet inter-arrival time to ensure that nodes along the path do not go to sleep during active communication. There are also some control messages, such as route reply messages in on-demand routing protocols, that provide a strong indication that subsequent packets will follow this route. Therefore, such messages should trigger a node to switch to active mode. The time scale of the keep-alive timer for such a transition should be on the scale of the end-to-end delay from source to destination so the node does not transition back to power save mode before the first data packet arrives. To sum up, the choice of different keep-alive timer values will provide different trade-offs between energy consumption and data delivery efficiency.

Since communication with a neighbor is only possible if the neighbor is in active mode, it is necessary for nodes to track energy management modes of neighbors. In our model, each node maintains a neighbor list that caches a neighbor's mode and a time-stamp of the most recent update from this neighbor.

The neighbor's power mode can be discovered in two ways [13]. The first way is through explicit local HELLO message exchanges with piggybacked information about the energy management mode of a node. HELLO messages should be transmitted at fixed intervals regardless of the mode of a node. Link failure is assumed

if no HELLO messages have been received during successive intervals, since the loss of only one HELLO message may have been caused by a broadcast collision. Another way is via passive inference. Compared to using HELLO messages, passive inference does not rely on additional control messages, which is more desirable from an energy conservation perspective. Note that the ambiguity of link failure and the energy management mode of a neighbor can result in some delay for data transmission.

### III. OUR PROPOSED ROUTING PROTOCOL

The idea of cross-layer design is used in our routing protocol. MAC protocol is responsible for switching energy management states of nodes and buffering data for sleeping nodes. It can broadcast a schedule depicting the transmission times for each mobile node, hence allowing the nodes to switch their power mode. Moreover, in a single-transceiver system, switching from transmit to receive mode is required to support both uplink and downlink communications. By providing a means for allocating contiguous slots for transmission and reception, power consumed as a result of transceiver mode switching can be reduced. In terms of channel reservation, power may be conserved by supported the request of multiple slots with a single reservation packet. From another perspective, considerable power savings can be obtained by intelligently turning of radios when they cannot transmit or receive packets.

The most of important function of the network layer is to support routing. In MANET, there are no base stations and each node acts as a router and packet forwarder. Hence, the computation and communication load can be quite highly, it is to say power control impacts on the routes employed. Vice-versa, the power control strategy needs connectivity information that is provided by the routing layer. This mutual dependency motivates the need for a joint solution for power control and routing. In this section, our proposed routing protocol can use the joint function which has relationship with residual energy and transmission power of nodes to find energy efficient path. Sometimes, subscribing and unsubscribing mechanism can be used in enhancement layer to reduce the number of transmitted as well as received packets.

Our routing protocol aims to find the optimal path which can reduce the energy consumption of mobile nodes and increase the life-span of network. Death of nodes due to energy exhausted may lead to the network partition and cause communication failure with other active nodes. To solve the problem, we need to choose the path with lowest energy consumption and balance the traffic load in network. The proposed protocol can provide hop-by-hop as well as end-to-end energy control. On one hand, it adjusts transmission power for per-hop to implement energy control. On the other hand, it discovery the feasible routes based on residual energy and transmission power of nodes so as to enhance the overall performance of network.

We use the extended version of DSR for routing. DSR is an on-demand routing protocol for MANET. Like any other source routing protocol, in DSR the source includes the full route in the packets' header. The intermediate nodes use this to forward packets towards the destination and maintain a route cache containing routes to other nodes. It consists of two phases, i.e., route discovery and route maintenance [15]. Some fields are added in RREQ, including the transmission power  $P_{tx}$  which can be dynamic adjusted, receive power  $P_{rx}$ , and residual energy of node  $E$ . With the knowledge of  $P_{txmax}$  and  $P_{rx}$ , the generic node is able estimate the link attenuation. In particular, when a station receives a packet from a neighbor, the channel attenuation is simply computed as the difference of the transmitted power  $P_{txmax}$  and the received power  $P_{rx}$ . For the simple case of a symmetric channel, where we neglect possible channel time fluctuations and we assume the same interference power level, the attenuation affecting the transmission of that station towards that neighbor would be the same as measured [4].

Assume that there are  $j$  feasible paths and each path includes  $i$  nodes, we can define the joint function  $L$  as follow:

$$L = \max_j \min_i (E / P_{tx})$$

Obviously, the transmission power coupled with the residual energy of nodes is considered in this function. It represents the tendency of energy consumption and can be used to evaluate time to live of link. Among all feasible paths, we chose the path with value  $L$  as the optimal route for transmitting data packets so as to achieve the end-to-end energy control.

In routing discovery process, any node in the network can initiate dynamic routing request to the other node. The communication by wireless transmission between the source and destination nodes can be directly within one hop or through other intermediate nodes. Besides the address of source node and destination node, RREQ packet includes routing list, request packet ID, transmission power  $P_{tx}$  and node residual energy  $E$  as mentioned above. Each RREQ packet must be unique and its number will be assigned by the source node. It can be identified by the address of the source node and request ID. When a RREQ is received by node  $i$ , the process can be described as follows:

**Step 1** If the current node is the destination node, it will calculate  $P_{tx}$  according to Eq. (1) and the ratio of  $E$  to  $P_{tx}$ . Then it adds the values to the corresponding fields of RREQ and produces RREP. The values recorded in RREQ will be copied to RREP. Finally, it begins to send RREP to the source node. Otherwise, go to step 2;

**Step 2** If the current node has already forwarded the RREQ, the RREQ will be deleted. Otherwise, go to step 3;

**Step 3** If the routing list in RREQ contains address of the current node, the RREQ will be deleted. Otherwise, go to step 4;

**Step 4** Calculate  $P_{tx}$  and continually forward RREQ. Go to step 1.

Once the destination node receives RREQ, it needs to select the path for responding the RREP to the source node. Since the RREQ records the routing list from the source to the destination node, destination node can reverse the route recorded in RREQ and send RREP along it. Assume that each pair of nodes have symmetric wireless communication channel in such case.

When a RREP is received by node  $i$ , the process can be described as follows:

**Step 1** If it is the source node, the process will be terminated. Otherwise, go to step 2;

**Step 2** If it is in power-save mode, call MAC protocol to transfer it to active mode;

**Step 3** Calculate the ratio of  $E$  and  $P_{tx}$ . If the value less than that recorded in RREP, the record will be replaced. Then it continues to forward RREP. Go to step 1.

Once RREP is received by source node, the feasible path is set up. The source starts a timer and during the period at most  $j$  RREPs are collected by the source node. Then the source node begins to calculate the function  $L$  based on the corresponding records in RREP and choose the path whose function value is  $L$  as the optimal route. Finally, data packets can be transmitted along this path with the transmission power recorded in RREP.

#### IV. PERFORMANCE EVALUATION

In this section, we evaluate our proposed protocol through simulation experiments. Different networks are randomly generated within a 1000×1000 square region. The bandwidth of wireless radio is 2Mbps and transmission radius between adjacent nodes is 200m. The IEEE 802.11 MAC protocol is used in the simulation model. Random way-point is selected as movement model and the CBR is used to send data. The length of data packet is 64Bytes and the initial energy of mobile nodes is 100J. In all cases, the results are based on the performance of 20 randomly generated networks.

We compare the performance of the joint function based routing with the shortest path based routing. CBR is used to send packets at different transmission rates. There are 30 nodes randomly generated in such scenario. Random way-point is adopted as the mobile model and the pause time of nodes is set to 50s. Figure 1 to 3 shows the energy consumption, span-time of network and average end-to-end delay as traffic load changes. The life-span of network is defined as the period from the beginning of simulation to the moment when all nodes exhaust their energy. The performance of both routing schemes degrade while traffic load increase. Especially, the energy consumption of the shortest path based routing grows drastically under high traffic, which results in poor survival time of network. When the traffic load is high, more packets need to be transmitted. In the joint function based routing, the optimal transmitting power is

calculated for sending packets so as to effectively save energy. Furthermore, since the residual energy of nodes is also considered in such routing function, it can achieve load balance and extend life-span of network. With the joint function based routing scheme, it needs to calculate the optimal transmitting power of the nodes in the routing setup stage. After the initial setup stage, however, data packets will experience similar latency as those in the shortest path based routing scheme. Note that the average end-to-end delay of the joint function based routing can be nearly to that of the shortest path based routing, while the energy saving is nearly doubled.

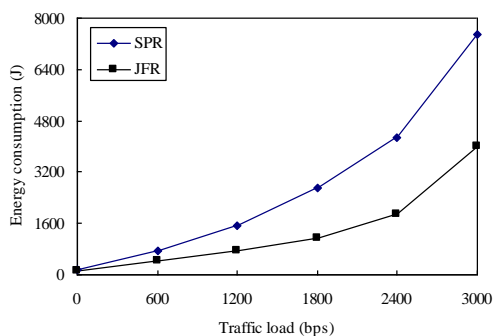


Fig. 1. Energy consumption

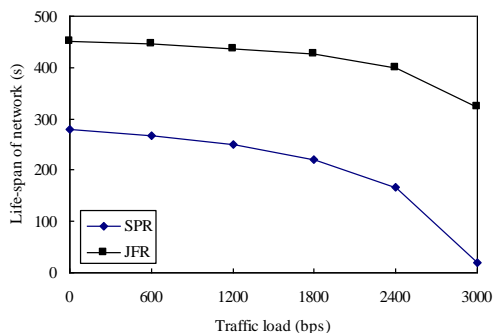


Fig. 2. Life-span of network

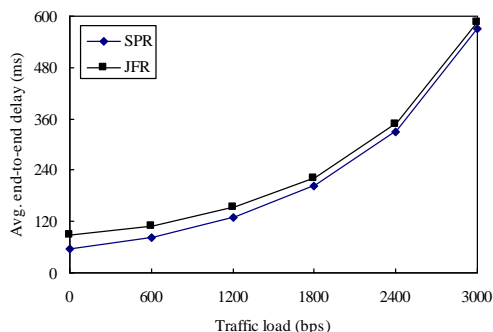


Fig. 3. Avg. end-to-end delay

## V. CONCLUSIONS

In this paper, we first present an energy management model, in which each node can transfer its state between power-save mode and active mode. Based on such model, we propose a routing protocol for further energy control. In the protocol, a new routing function dealt with both MAC layer and network layer is defined. It can

dynamically adjust transmission power of nodes for per-hop energy saving and, also consider the residual energy of node for balancing traffic load to achieve overall energy efficiency. Among the feasible paths, the one with the maximal value of joint function will be chosen as the optimal route for data transportation. Simulation results show that such protocol can remarkably increase the life-span of network with lower energy consumption when compared to the routing scheme according to the shortest path and without energy control mode.

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