Multi-rate Aware Routing Protocol for Mobile Ad Hoc Networks

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Abstract— **This paper introduces multi-rate aware routing scheme that helps to improve the resource utilization and to minimize the power consumption in mobile ad hoc networks(MANET). The existing MANET routing protocols (e.g., AODV, DSR and TORA) attempt to minimize the number of hops between source-destination pairs. These routing protocols are all designed under the assumption of using only single data rate in the wireless channel (e.g., IEEE 802.11). Currently, 802.11b supports the various data rate, 11Mbps, 5.5Mbps, 2Mbps and 1Mbps according to channel conditions between mobile terminals, through several modulation schemes that are optimized for channel conditions. So if we utilize these multi-rate support from MAC and physical layers when packets are routed in mobile ad hoc networks, we can achieve better performance in throughput and resource utilization. In this paper, we propose a Multi-rate aware sub layer (MAS) which is independent of IP protocol and enables the full utilization of the multi-rate channel characteristics. The key function of MAS is to change its next hop node to another node through which higher data rates are available, in the basis of two-hop neighbor information and link states. We show through simulation that multi-rate aware routing protocol outperforms traditional MANET routing protocols due to its utilization of multi-rate support.**

Key words: IEEE 802.11, Ad Hoc Networks, Routing Protocol, Wireless Packet Network

I. Introduction

A mobile ad hoc network (MANET) is a set of wireless mobile nodes forming a dynamic autonomous network though a fully mobile infrastructure. Nodes communicate each other without the intervention of centralized access points or base stations. DSR, AODV, and TORA routing protocols [1] were proposed for mobile ad hoc networks because existing wired routing protocols can not be used directly, due to high node mobility and wireless channel characteristics of MANET. These suggested protocols try to find the shortest routes between source-destination pairs and are independent of underlying MAC and physical layer such as single-rate or multi-rate support.

The original IEEE 802.11 protocol supports single base rate, typically 2Mbps [2]. But the most widely used IEEE 802.11a and IEEE 802.11b media access protocols provide a physical-layer multi-rate capability [3], [4]. With multi-rate enhancement, transmission can take place at a number of different rates according to channel conditions. Data rates higher than the base rate are possible when the signal-to-noise ratio(SNR) is sufficiently high. Consequently, with IEEE 802.11a the set of possible data rates is 6, 9, 12, 18, 24, 36, 48 and 54 Mbps whereas for IEEE 802.11b the set of possible data rates is 1, 2, 5.5 and 11 Mbps.

However, no effort has been made to utilize this multi-rate enhancement in mobile ad hoc networks so far. The existing routing protocols hardly take advantage of the multi-rate supported network interface due to the following reasons. In the IEEE 802.11 ad-hoc mode operation, broadcast packets are transmitted through the lowest data rate for improving the network connectivity, since the coverage of a node is inversely proportional to the transmission data rate. The problem is the fact that almost all routing protocols in MANET utilize the broadcasting message for searching the shortest path based on the hop-counts (i.e., the path of the minimum number of nodes) between the source node and the destination node. In the shortest path, the distance of each link between a pair of two nodes on the path is very long. In wireless mobile network, the bandwidth of a link gets much lower as the distance of the link gets longer. Thus, if the shortest path is used, the bottleneck capacity of the end-to-end path decreases. Consequently, it results in reducing the network throughput, also increasing the energy consumption and the packet delay.

Thus, if we use this enhancement effectively in MANET, we can achieve better performance in throughput and resource utilization. We propose multi-rate aware routing protocol for mobile ad hoc networks including Multi-rate Aware Sub layer(MAS) between Network and Link layer to utilize multi-rate characteristics. The remainder of this paper is organized as follows. The related works are introduced in Section II. In Section III, we present the multi-rate aware routing protocol. We present the result of simulation experiments in Section IV, and the conclusion in Section V.

II. Related work

PARO [5], power-aware routing is based on the principle that adding additional forwarding node (i.e., *redirectors*) between source-destination pairs significantly reduces the transmission power necessary to deliver packets in multi-hop wireless networks. By optimizing the routing path of each connection, PARO, operates in the network layer, can achieve the energy saving gain. The basic idea of both RARO and multi-rate aware routing proposed in the paper is likely. But, we optimize the routing path of each

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connection in order to provide higher bandwidth instead of just reducing the transmission power. In PARO, it is assumed that the transmit power of the network interface card changes and delivers the packet from source to destination through links using the low transmit power. However, it has many problems (e.g. causing the link asymmetry) although it has benefit of reducing the power consumption by changing the transmit power. Thus, we use the network interface model which is characterized by the fixed transmit power and the support of multi-rate according to channel conditions. (e.g, IEEE 802.11a and IEEE 802.11b)

III. Multi-rate Aware Routing Protocol

A. Problem Definition

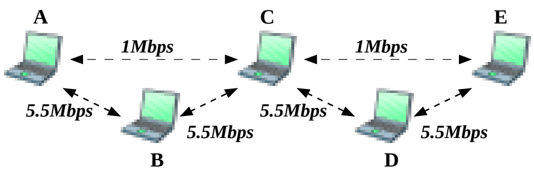

Fig. 1. Link States topology of Ad-hoc Networks

Fig. 1 represents a topology of mobile ad hoc networks with node connectivity and available data rate of each link. We assume that each node uses IEEE 802.11b so that each link has different data rate since data rate is related to the distance of two nodes. As Table I [6] shows, if the distance between two nodes is close enough to meet high Signal-to-Noise rate(SNR), higher date rates can be acquired.

TABLE I
Relation between the distance of two nodes and the available data rate

Range(meters)	11Mbps	5.5Mbps	2Mbps	1Mbps
Open	160m	270m	400m	550m
Semi-open	50m	70m	90m	115m
Closed	25m	35m	40m	50m

In the Fig. 1, MANET routing protocol(e.g., DSR or AODV) will select routes $A \rightarrow C \rightarrow E$, because it is based on shortest hop count. However, if we route data through $A \rightarrow B \rightarrow C \rightarrow D \rightarrow E$ instead of $A \rightarrow C \rightarrow E$, we can utilize higher link bandwidth. This may increase the number of hop count, consequently, the channel access overhead (e.g., backoff time) could be increased in proportion with hop count. However it can reduce link-level transmission time ($\simeq$ $Packet\ Size/Bandwidth$), which is highly affected by the packet size. By reducing transmission time, we can achieve better throughput and always reduce the total energy consumption in the network wide. Since the transmitting and receiving power consumptions are constant(e.g., 285 mA for Transmit mode and 185 mA for Receiver mode [6]), total powers consumed in the network is determined by the sum of each link transmission time.

We propose TCP/IP protocol stack enhanced with Multi-rate Aware Sub layer(MAS) as shown in the Fig. 2 for a multi-rate aware routing protocol. The detailed functions of MAS will be followed in the next subsection.

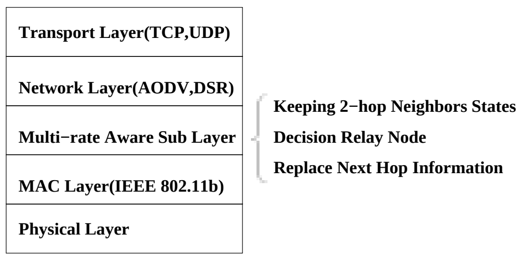

Fig. 2. Multi-rate Aware Routing Protocol Stack

B. Multi-rate Aware Sub Layer

The MAS always keeps track of two-hop neighbor's state information such as SNR, data rate of neighbor's incident link. This state information is maintained either by proactive(periodic HELLO message exchanges) or reactive(RTS-CTS-DATA-ACK exchanges) methods. In proactive method, a node periodically broadcasts HELLO message containing its neighbor nodes state information so that each node can get two-hop nodes' state information. In reactive method, MAS overhears RTS or CTS control messages and from which it can infer who are two-hop neighbor nodes and date rates of their incident links. For example, in the Fig. 1, if node A overhears the RTS which B sends to C, A can infer that C is B's neighbor so that A can send data to C via B.

The MAS changes its next hop node to the node through which higher data rates are available in the basis of two-hop neighbor information and link states. The Eq. (1) shows the condition when the MAS can changes its next hop of IP layer from dst to $relay$. In other words, MAS changes its next hop only when it can send data in a shorter transmission time.

$$\frac{1}{Data\_Rate(src \rightarrow relay)} + \frac{1}{Data\_Rate(relay \rightarrow dst)} < \frac{1}{Data\_Rate(src \rightarrow dst)}, relay \in neighbor\_set(src) \quad (1)$$

In Fig. 1 when there is a packet to send from $node\ A$ to $node\ E$, Network Layer protocol choose the shortest route $A \rightarrow C \rightarrow E$. The MAS of $nodeA$ sees that the next hop is $node\ C$, but it knows that via $nodeB$ would satisfy the above equation, which means we can reduce the transmission times, change its next hop to $node\ B$.

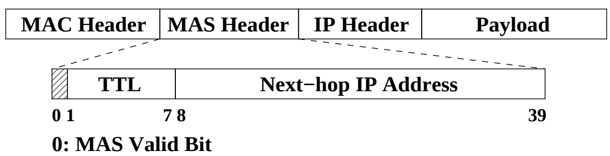

Fig. 3. Header format for Multi-rate Aware Sub layer(MAS)

The Fig. 3 presents the header format used in MAS. MAS header of 5 byte is located on between the MAC header and IP header. First bit presents the valid state of this MAS header information. When this valid bit is set, it means that this packet will be relayed to another node which is different from the node determined by the IP layer. So, if the node receiving the packet whose valid bit is set from lower layer (i.e. MAC layer), it does not send this packet to the higher layer (i.e. IP layer) since this node is just relay node and not next hop of the previous node. The next 7 bits presents the time to live(TTL) for restricting packet relayed count through MAS and solving routing loop problems, occurring rarely, due to nodes' mobility. Last 32 bits presents the next hop's IP address to which this packet is forwarded by IP routing protocol. If the MAS received the packet from higher layer at first, MAS searches the relay node through which this packet is transmitted to the the next hop node with higher bandwidth. When the next hop node is changed, MAS records this information into the next hop address field in the MAS header. The Algorithm 1 presents the pseudo code of function occurring when the MAS receives the new packet from lower and higher layers.

Algorithm 1 $MAS :: Receive(Packet\ *p)$

```
hdr_cmn *ch := hdr_cmd(p);
hdr_mas *mh := hdr_mas(p);
if mh → valid() then
   ch → direction() := hdr_cmn :: down;
   next_hop := mh → mas_addr();
end if
if ch → direction() = hdr_cmn :: up then
   send_up(p);
   return;
end if
if ch → ptype() = unicast then
   Min_cost := 1 / Data_Rate(this→next_hop);
   while k ∈ neighbors_set(this) do
      cost := 1 / Data_Rate(this→k) + 1 / Data_Rate(k→next_hop);
      if cost < min_cost then
         min_cost := cost;
         relay_node := k;
      end if
   end while
   if next_hop ≠ relay_node then
      mh → mas_addr() := next_hop;
      next_hop := relay_node;
      mh → mas_valid() := 1;
   else
      mh → mas_valid() := 0;
   end if
end if
send_down(p, next_hop);
```

IV. Simulation Experiment

We have simulated DSR extended with multi-rate aware sub layer(MAS) using $ns-2\ simulator$. First, we run our simulation with simple topology in Fig. 1 and TCP traffics between *node A* and *node E*. Then we run our simulation in a random topology with 30-node networks in square regions of area of 1000 X 1000 meters. For mobility experiments, the motion of the 30-nodes follows this random way point model: initially, each node chooses a destination uniformly at random in the simulated region, chooses speed uniformly at random between 0 and 5 m/s, and moves there with the chosen speed. The node then pauses for an adjustable period of time, 10 seconds, before repeating the same process. We use 10 FTP applications with packet size of 512 byte as traffic pattern.

In the next two figures, we compared the throughput and power consumption of multi-rate aware routing protocol with those of base-rate routing protocol with varying packet size, in simple topology. In Fig. 4, we show the ratio of multi-rate aware routing protocol throughput(Mbps) to base-rate routing protocol throughput(Mbps). We see that with a large packet size, a large amount of reduction in transmission time can be achieved with multi-rate aware routing protocol, consequently leading to high throughput ratio. We can also see better throughput with a small packet size.

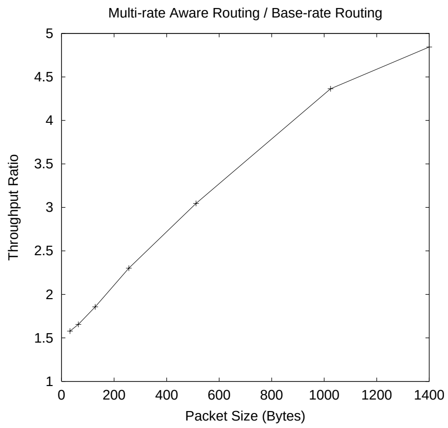

Fig. 4. Throughput ratio in simple network topology

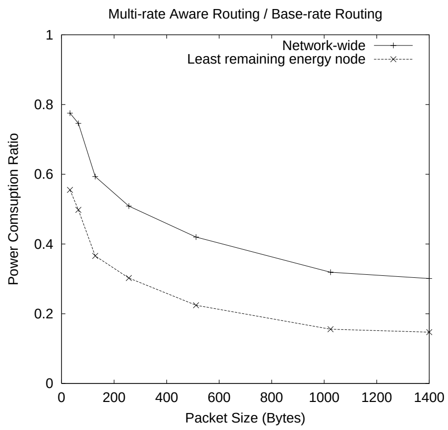

Fig. 5. Power consumption ratio in simple network topology

In Fig. 5, we show the ratio of multi-rate aware routing protocol power consumption to base-rate routing protocol power consumption from source to destination pairs for transmitting unit byte. The total power consumption ratio in the network-wide for each varying packet size and the the power consumption ratio of the least remaining energy node are shown. We see that with multi-rate aware routing protocol, a large amount of reduction in power consumption can be acquired due to the reduction of transmission time.

In the next three figures, we compared the throughput, power consumption and end-to-end packet delay of multi-rate aware routing algorithm with those of base-rate routing algorithms, in random topology with mobile nodes. In Fig. 6, we show the throughput(Mbps) of both multi-rate aware routing protocol throughput and base-rate routing protocol during 1000(s). The Y-axis presents the sum of all FTP connections' goodput, purely transmitted byte excluding the retransmitted byte caused by TCP retransmission. As you can see, multi-rate aware routing using MAS always outperforms the base-rate routing protocol (2X at maximum).

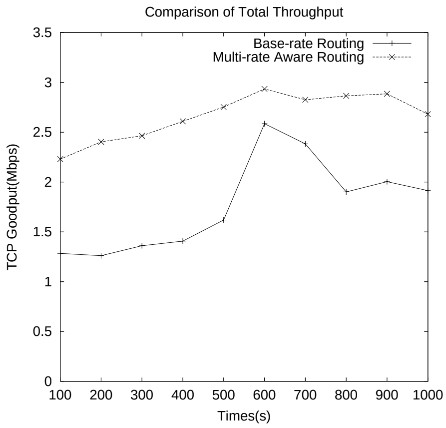

Fig. 6. Throughput comparison in random network topology(1000mX1000m)

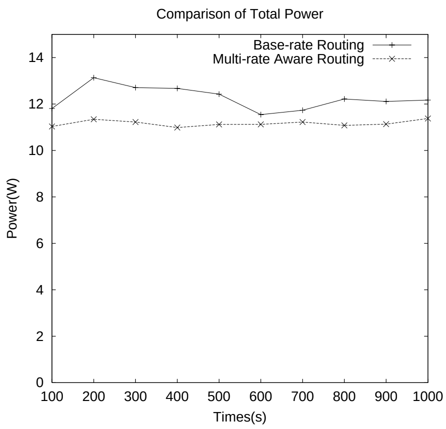

Fig. 7. Power consumption comparison in random network topology(1000mX1000m)

In Fig. 7, we show the power consumption(W) of both multi-rate aware routing protocol throughput and base-rate routing protocol during 1000(s). The Y-axis presents the sum of all nodes' power consumption. We can see that multi-rate aware routing consumes less power than the base-rate routing. Through the simulation results of both Fig. 6 and Fig. 7, we can apparently know that the multi-rate aware routing protocol provides superior energy-efficiency since, with less energy consumption, the multi-rate aware routing protocol achieves higher throughput than the base-rate routing protocol.

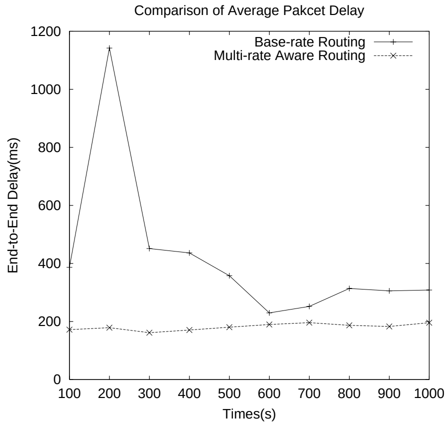

Fig. 8. Packet delay comparison in random network topology(1000mX1000m)

In Fig. 8, we show the end-to-end packet delay(ms) of both multi-rate aware routing protocol and base-rate routing protocol during 1000(s). The Y-axis presents the average 100(s) interval's end-to-end packets delay of all transmitted packet (i.e. all TCP data and ack packets). The multi-rate aware routing provides the delay lower than 200(ms) during the all simulation period. Moreover, it provides the lower delay-jitter than the base-rate routing protocol.

V. Conclusion

In this paper, we have presented multi-rate aware routing protocol in mobile ad hoc networks enhanced with multi-rate aware sub layer (MAS). The key function of MAS is changing its next hop node to another node through which higher data rates are available in the basis of two-hop neighbor information and link states. We evaluated multi-rate aware routing protocol in mobile ad hoc networks enhanced with MAS using $ns-2\ simulator$. The evaluation results show that we can achieve better throughput, less power consumption and less packet delay through our proposed algorithms which is independent of packet size and mobility of nodes.

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