A Novel Approach for an Optimized Route Discovery and Packet Forwarding for Ad-hoc Networks Using Multi Rate Routing Protocol

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Abstract: Ad hoc On-Demand Distance Vector (AODV) Routing is a routing protocol for mobile ad hoc networks (MANETs) and other wireless ad-hoc networks. The traditional AODV protocol cannot address to multi rate PHY communications. In this project, we analyze the relationship between data rate, corresponding transmission range and number of hops in AODV protocol and find the optimal data rate for AODV control and data packets and effective routing metric. Then we propose a new cross-layer AODV routing protocol namely Multi-Rate AODV (MR-AODV) to establish efficient routes in the multi-rate wireless environments. MR-AODV propagates the RREQ packets at the optimum rate to disseminate them faster and the path selection algorithm chooses the best multi rate path for the communication. This also introduces a new routing metric namely path gain that is used to select the optimal route between the source and destination nodes. This approach acquires information from the MAC layer and rate controlling from the network layer. The performance of this enhancement has been evaluated by simulation using Network Simulator and results show significant improvement of the performance in multi-rate ad hoc network environments.

Key words: Ad hoc % MANETs % MR AODV

INTRODUCTION

Wireless ad hoc networks are composed of a number of autonomous wireless nodes and are capable of communicating with each other over direct wireless links within the coverage or with the help of intermediary hops when they are out-of range from each other. Therefore, each node in the network has to act as a router to provide end–to–end connectivity between two non-neighboring nodes [1].

A number of routing protocols for such networks have been proposed in the recent years; however, due to the dynamic nature of wireless environment and the node mobility, the reactive or on–demand protocols are preferred rather than the proactive protocols. The Ad hoc On–demand Distance Vector (AODV) protocol [1] is one of the popular *reactive* routing protocol that discovers the path between the source and destination nodes dynamically.

Nowadays, physical layer enhancements support multiple data rates, which enable wireless nodes to select the appropriate transmission rate depending on the required quality of service and the radio channel conditions. However, the receiver sensitivity or the minimum received signal strength at the receiving end varies with the data rate. The receiver can receive high rate transmissions when it receives stronger signals. Since the radio signal attenuates exponentially with distance, the higher receiver sensitivity for the higher rates cause the transmission range to drop below the range with lower data rates. As a result, the cell size decreases when wireless nodes selects higher data rates and the number of hops between two nodes increases [2], [3].

The IEEE 802.11 standard does not include any specific rate adaptation technique to utilize the multiple transmission rates efficiently; rather it leaves that as an implementation dependent issue [4]. We observe many proposed rate adaptation schemes like the *Automatic Rate Fallback* (ARF) scheme is widely-adopted by the industries. However in ARF, broadcast packets are never acknowledged, hence those packets are always transmitted at the highest possible rate.

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Awerbuch [5] showed the efficiency of the medium time metric in selecting high throughput network metric yields an average total network throughput increase of 20% to 60%, depending on network density, over the traditional hop count. The SSR [6] and HT-AODV [7] routing protocols focus on the high throughput path selection. However, they do not consider the rate efficiency in transmitting the RREQ packets. The hop count routing metric, which is traditionally used in single rate networks, is suboptimal in multi-rate networks as it tends to select short paths composed of maximum length links. In a multi-rate network, these long distance links operate at the slowest available rate, thus achieving low effective throughput and reduced reliability. Signal Stability Based Ad Hoc Routing Protocols as in [8], the authors show that the minimum hop path generally contains links which exhibit low reliability. In [9] the authors present various routing protocols which are based on signal stability and link reliability rather than just shortest path in order to provide increased path reliability. On the contrary, in our work, signal information is used not only to increase the path's reliability, but also to increase network throughput.

In [10] the authors propose a Rate Adaptive Opportunistic Ad hoc Routing (ROAR) protocol [11]. The ROAR, however, relies on the transmission failure count for rate adaptation. Therefore, it does not adapt the rate during route request phases to propagate the requests faster. In the proposed models for MR-AODV [12], the parameters introduced, adds on to unnecessary network overheads and the directional dependence of the signal attenuation is portrayed in an excessively significant manner. Also redundant computation is introduced in [13] as the same value of data rate is calculated twice for each link on both the nodes. This could be a huge disadvantage in a congested network in which, with an increase in the processing time of each packet increases the delay at each node and hence the network recovery phase.

Hence, we propose a new cross-layer scheme to enhance the AODV protocol namely Multi-Rate AODV (MR-AODV) to establish efficient routes in the multi-rate wireless environments. The MR-AODV introduces a new routing metric namely Path Gain that is used to select the optimal data rate for data transfer. The path gain is calculated considering both hop count and data rates at each hop for a given path. The optimal data rate for links at each hop is found and therefore the end-to-end performance is improved. The cross layer design of

MR-AODV enables acquiring information from the MAC layer and rate controlling from the network layer and it does not require any rate controlling protocols at the MAC layer, reducing the computational complexity. MR-AODV propagates RREQ packets at the optimum data rate to disseminate them faster and the path selection algorithm chooses the best multi-rate path for the communication.

The Optimum Data Rate

Data Rate vs. Hop Count: The layer independent design of AODV and the ARF scheme jointly force to transmit the RREQ at the highest possible rate. As a result, the number of hops in the routes increases. Moreover, a node can be isolated from the network when it has no neighbour within the range of the highest rate. On the other hand, if the rate control were designed to allow transmitting broadcast/multicast packets at the lowest possible rate, the airtime of the RREQ packet would increase significantly. It would also flood the network during the route discovery. Therefore, the performance of AODV protocol in ad hoc networks with multi-rate supported devices depends on the trade-off between the data rate and number of hops [14].

Calculating the Optimum Data Rate: In this section, we present an analytical model to determine the optimum data rate for ad hoc communication. First, we relate the minimum number of hops with the data rate and then find the gain in transmission time for selecting higher data rates. Finally, we combine them to find the optimal data rate for multi-hop ad hoc communications. According to the wireless radio propagation model, the received signal strength at a receiver R, which is d distance away from the transmitter T, is expressed as:

$$P_r = P_t - 20\log_{10}\left(\frac{4\boldsymbol{p}\,\overline{d}\,f}{c}\right) - 10\boldsymbol{g}\log_{10}\left(\frac{R_t}{\overline{\overline{d}}}\right)dBm. \qquad (1)$$

where, P_r and P_t are the receive and transmit signal power in dBm, $20\log_{10}\left(\frac{4\boldsymbol{p}\,\overline{d}\,f}{c}\right)$ is the free space path loss at a reference distance $\overline{d}$ (usually, 1m) in dBm for signal speed of c and frequency f and $\boldsymbol{(}$ is the path loss exponent $(1.6\#\ (\#6)$ depending on the channel condition between T and R. For any modulation and coding scheme, if the receive sensitivity P_{si} is required for transmission rate i, we can determine the transmission range Ri from (1) with $\overline{d}$ = 1 and $P_r = P_{si}$ as:

$$R_i = 10^{\frac{P_t - P_{s_i} - 20\log_{10}(4\boldsymbol{p}\, f\,/\,c)}{10\boldsymbol{g}}} \qquad (2)$$

Range Gain: The Range Gain (G_{Ri}) is the ratio of the transmission range for data rate 'i' to the transmission range for the minimum data rate min(i), which can be expressed as:

$$G_{R_i} = \frac{R_i}{R_{\min(i)}} = 10^{\frac{-P_{s_i} + P_{s_{\min(i)}}}{10\boldsymbol{g}}} \qquad (3)$$

Hop Count: The Hop Gain G_{hi} is the minimum number of hops required by the data transmission at rate i to cover the transmission range of data rate min(i),

i.e., $G_{h_i} = \left[\dfrac{1}{G_{R_i}} \right]$ $\qquad (4)$

The G_{hi} shows how a data rate affects the performance of the network by increasing (decreasing) the number of hops.

Let us consider OFDM technology applied at the physical layer. The IEEE 802.11g standard with OFDM technology support eight modulation and coding schemes (MCS) and offers eight data rates between 6Mbps to 54Mbps according to the selected MCS as shown in the Table 1. The 802.11 OFDM PHY transmission time for a packet is given by:

$$t_i = t_P + t_{SIG} + \left[\frac{16 + 8*L + 6}{N_{DBPS_i}} \right] * t_{SYM} \qquad (5)$$

L is the payload size in bytes including the network and MAC overheads, t_P, t_{SIG} and t_{SYM} are the PREAMBLE, SIGNAL and OFDM symbol transmission time and N_{DBPSi} is the number of coded bits per OFDM symbol for the selected data rate *i*, respectively. The IEEE 802.11 standard defines these values as 16µs, 4 µs and 4 µs, respectively

Combining (4) and (5), the rate gain G_i can be defined as:

$$G_i = G_{h_i} \left(\frac{\overline{t_a} + t_i}{\overline{t_a} + t_{\min(i)}} \right) \qquad (6)$$

where $t_{min(i)}$ is the transmission time of the packet at the minimum rate and t_a is the average access delay at each hop including the time to transmit the packet in the queue

Table 1: Data Rate vs. Receiver Sensitivity in IEEE 802.11 OFDM PHY

Data Rate *i* (Mbps)	Modulation M_i	Coding C_i	bits/sym N_{DBPS_i}	Rx Sensitivity P_{s_i} (dBm)
06	BPSK	1/2	24	−82
09	BPSK	3/4	36	−81
12	QPSK	1/2	48	−79
18	QPSK	3/4	72	−77
24	16-QAM	1/2	96	−74
36	16-QAM	3/4	144	−70
48	64-QAM	1/2	192	−66
54	64-QAM	3/4	216	−65

Table 2: Gains in IEEE 802.11 ODFM PHY ($\boldsymbol{g}$ = 3.0, *ta* = 34µs, L = 1056 BYTES)

Data Rate (Mbps) *i*	Gains			
	Range G_{R_i}	Hop G_{h_i}	Link G_{l_i}	Rate $G_i = G_{h_i} \times G_{l_i}$
6	1.00	1	1.00	1.00
9	0.93	2	0.68	1.36
12	0.79	2	0.52	1.04
18	0.68	2	0.36	0.72
24	0.54	2	0.28	0.56
36	0.40	3	0.20	0.59
48	0.29	4	0.16	0.63
54	0.27	4	0.14	0.58

and MAC access delay. The access delay t_a at a hop depends on the number of active neighbours and the network load in the vicinity.

The $\left(\dfrac{\overline{t_a} + t_i}{\overline{t_a} + t_{\min(i)}} \right)$ is the gain in transmission time of the packet. We can assume the $t_a = 34$µs (the DIFS period) in a lightly loaded environment where the packet access the medium at the minimum possible time. In dense and high load networks $\overline{t_a} \gg t_i$; therefore, (6) can be represented as:

$$G_i \simeq \begin{cases} G_{h_i} & , \text{when } \overline{t_a} \gg t_i \\ G_{h_i} * \left(\dfrac{\overline{t_a} + t_i}{\overline{t_a} + t_{\min(i)}} \right) & , \text{otherwise} \end{cases} \qquad (7)$$

i.e., the number of hops in the path dominates the performance when a packet experience large access delay at each hop. Therefore, transmitting at the lowest rate would give the best performance in such a case.

Table 2 shows different rates with corresponding gains for the IEEE 802.11 multi-rate OFDM PHY. We observe that the rate with the smallest gain (i.e., 24Mbps) is the optimal rate in propagating the packet towards the transmission boundary. Therefore, the data rate *i* with minimum rate gain is the optimum for RREQ packet propagation [15].

Route Discovery: MR-AODV builds routes using a route request / route reply query cycle. When a source node desires a route to a destination for which it does not already have a route, it broadcasts a route request (RREQ) packet across the network. Nodes receiving this packet update their information for the source node and set up backwards pointers to the source node in the route tables. In addition to the source node's IP address, current sequence number and broadcast ID, the RREQ also contains the most recent sequence number for the destination of which the source node is aware. A node receiving the RREQ may send a route reply (RREP) if it is either the destination or if it has a route to the destination with corresponding sequence number greater than or equal to that contained in the RREQ. If this is the case, it unicasts a RREP back to the source. Otherwise, it rebroadcasts the RREQ. Nodes keep track of the RREQ's source IP address and broadcast ID. If they receive a RREQ which they have already processed, they discard the RREQ and do not forward it.

Route Selection: When the destination node responds for a RREQ packet with a RREP, it will have to affix an initial value of path gain. Initially the path gain value is kept as the data rate from the destination to the previous node. Thereby RREP packet propagates along the path cumulatively adding the data rates to the path gain till it reaches the RREQ originator. At the source, the source receives multiple RREP packets along different paths with different values of path gain. The source now calculates the actual path gain value as the data rate per hop for all the RREP packets and selects the RREP which has the highest value of path gain. This is the path which supports the highest data rate for transmission.

Path Gain Calculation: The path gain is the average data rate that can be achieved for data transfer towards the destination. Consider a path between two nodes x and y with n number of intermediary hops (n$0). Then the path gain G_p is expressed as:

$$G_p = \frac{\sum_{k=0}^{n+1} Dr_i(k)}{n} \qquad (8)$$

The path gain G_p is the routing metric used in MR-AODV. The data rate that can be applied on a link is found as follows:

Fig. 1: The Route Reply (RREP) Packet FOR MR-AODV

When a node receives a RREQ packet the MAC layer delivers the received packet to the network layer along with the RSSI for the packet and computes the data rate corresponding to the RSSI from Table 1. It then checks its routing table and enters this value of data rate in the path gain field for the sender node. If the node does not contain an entry in the routing table, it makes a new entry and stores this value of data rate as path gain. In a similar manner the data rates for each link is calculated and eventually each node knows the optimum data rate for data transfer with other nodes.

MR-AODV Packet Format: As discussed earlier, MR-AODV exploits the multi-rate capability in the in the PHY layer to route packets efficiently to the destination node. It follows the basic route discovery and routing phase of the AODV; however, it applies path gains as routing metric rather than the hop count alone as in traditional AODV. It retains the same packet format as in traditional AODV for the route request packets i.e., RREQ packets.

Rrep Packet Format: We modify the RREP packets of the traditional AODV protocol in order to apply the Path Gain Gp as the new routing metric. Since the MR-AODV follows the basic AODV protocol for the route discovery process, we keep the traditional AODV fields in these packets and append required gain fields to the packet [16].

The modified RREP packet structure is shown in Figure 5.2 It has an additional field namely Path Gain containing a single precision IEEE 854 floating point number. This field represents the path gain from the destination to the k-th hop (or the source). The routing algorithm uses this value as the new routing metric to route the packets efficiently.

Required Support from the MAC Layer: The proposed MR-AODV routing protocol requires cross layer support from the MAC for the computations of gains and to force
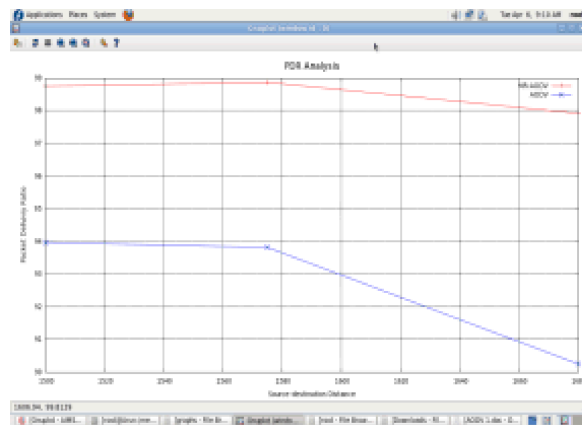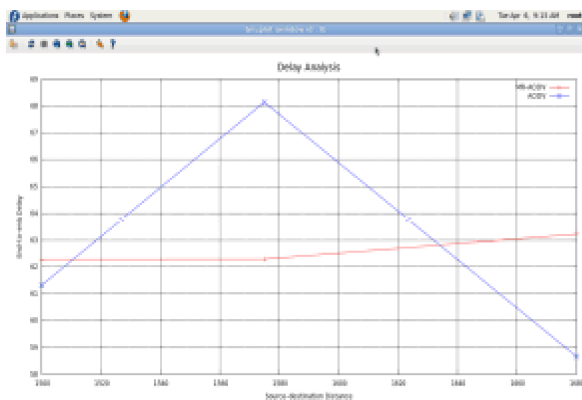
Fig. 2: PDR graph plotted for AODV and MR AODV

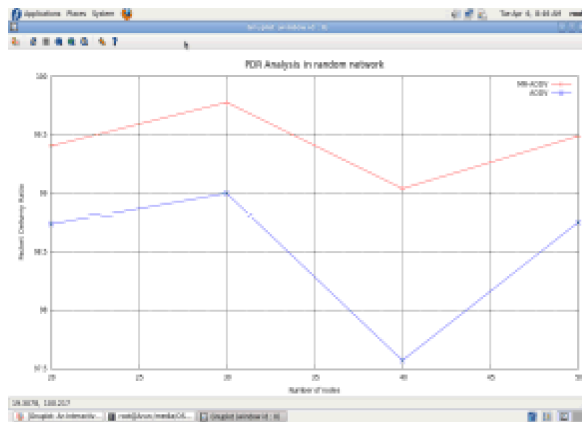Fig. 3: Delay graph plotted for AODV and MR AODV

Fig. 4: PDR graph plotted for AODV and MR AODV

the PHY layer to transmit packets at the desired data rate. The MAC layer delivers received data packets to the network layer along with the RSSI for the packet from which the network layer computes the Gains and rate controlling. Similarly, the network layer sends the control and data packets to the MAC layer with the desired data rate of transmission. The MAC layer

bypasses the rate control mechanism as in ARF and makes the PHY layer transmit the packet at the desired data rate.

Performance Analysis: The traditional AODV protocol uses the hop count metric for route selection. Instead we include the data rate also as a routing metric and provide a more efficient route selection algorithm. We evaluate the performance of the MR-AODV routing protocol by simulations on two different topologies and compare them with traditional AODV protocol. The simulations are run on the network simulator NS-2.33 and the results are analysed using graphs. We used a 20-node static topology with a varying inter-node distance and a random topology with varying node count. The load is applied at one end towards the other end. The data packet size is 1460 bytes and the path loss exponent (ã) for the channel is considered to be 3.

Scenario I: The observed packet delivery ratio and delay time of the MR-AODV protocol in the static topology have been shown in Figure 3 and 4, respectively

The packet delivery ratio is found to be greatly enhanced from that of the traditional AODV's performance with an average of 99% maintained. When the network spacing is increased both the protocols degrade in performance but the decline is found to be sharp and predominant in AODV, whereas our proposed model despite of the decline, still maintains a comparatively high PDR which is admitted from the graphs [17].

AODV and MR-AODV have similar performance in end to end delay when the source and destination were kept closer. This is because; the packet processing time becomes influential when very few hops are involved. However, when the node spacing is increased or when the end-to-end distance increases, AODV performs poorly in response with the delay variations being drastic. MR-AODV has a stable delay with very little variations for increased node spacing [14].

The delay is also predictive thereby reducing the analytical complexity. This can be explained as our protocol seeks more closely packed routes thereby using links that have better connectivity. Hence even with increasing distance the connection orientation is not greatly modified allowing a stable performance.

Scenario II: The random topology that is used here has a varying node count. The test scripts were run with 20, 30, 40 and 50 nodes. The network was allowed to monitor for some time before node mobility was allowed.
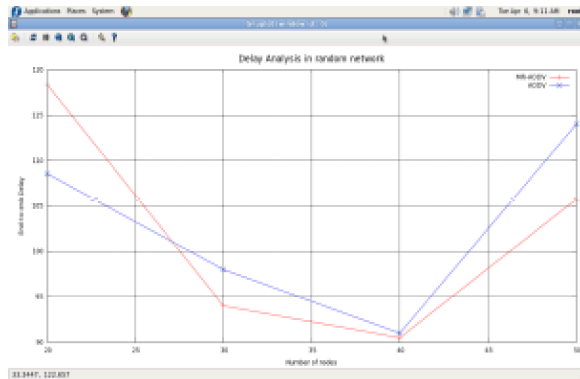
Fig. 5: Delay graph plotted for AODV and MR AODV

Both AODV and MR-AODV are severely affected by random topologies when the delay analysis is involved. However the better connectivity of MR-AODV helps it to perform slightly better than the traditional AODV. But when the PDR analysis is considered the MR-AODV protocol again produces a very high PDR above 99%.

CONCLUSION

In this project, we consider a new routing metric namely Path Gain for the multi-rate PHY in wireless ad hoc networks and propose an efficient routing protocol to select the most efficient routes using the Path Gain metric. The proposed MR-AODV disseminates the data packets very rapidly toward the destination. The selection of path with the maximum Path Gain also improves the network throughput in multi-rate wireless ad hoc networks [18]. The design of MR-AODV protocol requires support from the lower layers to control the PHY data rate as well as to receive information for the path selection algorithm. It also requires not using any rate controlling algorithms in the MAC layer.

Future Scope: The approach of multiple data rate discussed in our project can be modified to identify high throughput links. It can be adapted to trace the variations in data rate along each link in the path and the path which has the lower variations can guarantee better throughput. This is because when there is little variation in the links, it infers that those links have similar data rates. Therefore there will be fewer bottleneck links along the path and the need for extended buffers is reduced. Reduced buffering transpires as reduced packet discard thereby attempting to achieve very high throughput. This type of connection establishment could be applied where secure links are involved and packet retransmission is a concern for worry [13].

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