A Multi-Rate Routing Protocol with Connection Entropy for Mobile Ad Hoc Networks *

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ABSTRACT

In Mobile Ad hoc Networks (MANETs), when mobile nodes move to another location, the relative distance of communicating nodes will directly affects the data rate of transmission. The further distance between two communicating nodes is, the lower rate that they can use for transferring data. The connection certainty of a link also changes because a node may move closer or far away out of communication range of other nodes. Taking into account those issues, this paper proposes a new routing metric for MANETs. The new metric consider both link weight and route stability that be defined in relation with connection entropy. The problem of determining the best route is subsequently formulated as the constrained minimization of an object function formed as a linear combination of the link weight and and the uncertainty of connection of that link. The simulation results show that proposed routing metric improves end to end throughput and reduces the percentage of link breakage and route reparation.

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Keywords

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1. INTRODUCTION

Wireless mobile ad hoc networks are composed of a number of autonomous wireless nodes under the consideration of dynamic topology due to node mobility. Those nodes are capable of communicating with each other over direct wireless links within the coverage or with the help of intermediary nodes when they are out of range from each other. Therefore, each node in the network has to act as a relay node to provide end to end connectivity between two non-neighboring nodes. A number of routing protocols for such networks have been proposed in the recent years. However, the reactive or on demand protocols are preferred rather than the proactive protocols due to the dynamic nature of wireless environment and the node mobility. Routing algorithms are required to be flexible and to adapt quickly to changes in network topology and demand patterns. It must be able to operate under unexpected conditions of the network and must recover quickly from component failures.

Consider the multi-rate mobile ad hoc networks, there is a direct relationship between the rate of communication and the transmission range. Since distance is one of the primary factors that determines wireless channel quality, there is an inherent trade-off between high transmission rate and effective transmission range. Low speed link can cover the distance to the destination in few hops, while high speed link require more hops to reach the destination. It means that high speed route must deal with more risk of broken links and route discovery delay due to node mobility and the extra hops to the destination. In this paper, to avoid selecting an unstable route even though it is the high speed one, we investigate the connection uncertainty of a link in the manner that some nodes move infrequently than some other nodes in the networks. Hence, by choosing those stable nodes for communication route, we can reduce the probability of link breakage and route reparation. Moreover, the route speed is also be considered with route stability in the proposed routing metric.

The remain parts of the paper is organized as followed: Section 2 discusses about some existing work in routing for MANETs in general as well as for multi-rate wireless networks in specific. Next, section 3 introduces the related parameters used in the routing metric. The multi-rate routing is proposed in section 4 and the performance analysis are given in the section 5 to show the effectiveness of the new routing metric in term of throughput improvement, and link breakage and route repair deduction. Finally, section 6 gives some discussions and conclusions about the paper.

2. RELATED WORK

A lot of routing protocols have been proposed for the wireless ad hoc networks, which are followed one of two major strategies: proactive such as in DSDV [10] and OLSR [3] and reactive (on-demand) such as in AODV [9] and DSR [7]. These protocols were originally designed for single-rate networks, and thus have used a shortest path algorithm with minimum hop count metric to select paths. Min hop is an excellent criteria in single rate networks where all links are equivalent. However, it does not perform well in the multi-rate wireless network because it does not utilize the higher link speed for data transmission.

The Ad hoc On demand Distance Vector (AODV) protocol [9] is one of the popular reactive routing protocol that discovers the path between the source and destination nodes dynamically. In AODV, when the source node want to communicate with a destination node, it will broadcast a Route Request (RREQ) packet to the network. The neighboring nodes, which receive the RREQ packet, search for an existing route to the destination in its routing table. If there is a route already exist, the intermediate node replies with an unicast Route Reply (RREP) packet to the RREQ sender. Otherwise, it forwards the RREQ packet to its neighbors. By this way, the RREQ packet traverses hop by hop and reaches the destination. The destination node replies with an RREP to establish a new route by sending the packet traverses the same path in the reverse direction. When the source node receives multiple copies of RREP packets for the same RREQ packet, it selects the path with the minimum number of hops. The Hello and Route Error (RERR) packets is used to manage route failure and reconstruction. The design of AODV protocol is based on the simple packet radio model without the consideration of data transmission rate. The main problem of AODV is based on hop count, which can avoid to choose the highest data rate route.

Nowadays, physical layer enhancements support multiple data rates, which enables wireless nodes to select the appropriate transmission rate depending on the required quality of service and the radio channel conditions. For example, the IEEE 802.11g standard [6] with OFDM technology support eight modulation and coding schemes (MCS) and offers eight data rates between 6Mbps to 54Mbps according to the selected Modulation and Coding Scheme (MCS) as showed in the Table 1.

For multirate wireless ad hoc networks, several work on routing protocol was proposed. Awerbuch et. al. in [2] showed the efficiency of the medium time metric in selecting high throughput route. The author in [5] introduced an approach for multi rate MANETs to improve traditional AODV routing protocol. The proposal based on the link cost which is simply provided by delay time for transfer a packet from MAC layer which is inherited from [2]. For mobile ad hoc networks, that simple metric does not guarantee that routing protocol can choose the most stable route. Consequently, the probability that the chosen route is broken is very hight in the mobile environment. Nicolaos et. al. in [8] proposed routing metric for communication network using the new metric with connection probability approach. [8] also introduces the concept of link cost. However, they did not specify how to calculate the link cost for their routing metric.

In this paper, we define a link weight based on the relative distance and data rate of two communicating nodes. Also, we exploit stability aspect of connection entropy in [8]. Consider both the stability of a route and the speed of each link (represented by the link weight which is combined with the probability of that link existing in the route), we proposed a new routing metric for mobile ad hoc networks (MANETs). The new routing metric guarantee a found route has high speed and stability among route candidates. Therefore, this reduces the probability of link brakeage and route reparation especially in case of more frequently changing network topology.

3. PARAMETERS SUPPORTING MULTI RATE ROUTING FOR MANETS

The proposed multi-rate routing for Mobile Ad hoc Networks environment deals with the mobility problem by a totaly new approach. The traditional way to find an efficient routing metric for MANET is to deal with velocity and direction of node mobility. Instead, in this paper, the mobility is considered under the fact that the data rate will be changed and the chosen route is stable or not. Therefore, we define *Link Weight* (as the representative of data rate) and *Connection Uncertainty* (as the representation of route stabilization) in this section. Those parameters are used for further calculation of routing metric in the next section.

3.1 Support Calculate Link Weight from MAC Layer

For transmitting data at a specific rate ν (ν = (0, 6, 9, 12, 18, 24, 36, 48, 54) Mbps), the corresponding receiver sensitivity requirement is needed. In which, $\nu = 0$ means that node x and node y do not directly connect due to interference or out of communication range. Remind that the number of rate levels as well as the maximum data rate here follow the IEEE 802.11g standard [6]. Hence, if the network uses another standard, those parameters should be changed corresponding to that standard specifications. Table 1 shows the data rate and Rx Sensitivity in IEEE 802.11 OFDM PHY.

Hence, to transmit data at rate ν, the received signal strength must at least equal to the receiver sensitivity P_{S_ν}. The received signal strength at receiver R with distance d far away from the transmitter T is calculated as:

$$P_r = P_t - 20\log_{10}\left(\frac{4\pi\overline{d}f}{c}\right) - 10\gamma\log_{10}\left(\frac{R_\nu}{\overline{d}}\right)\ (dBm) \quad (1)$$

in which, P_r and P_t are the receive and transmit signal power in dBm, $20\log_{10}\left(\frac{4\pi\overline{d}f}{c}\right)$ is the free space path loss at a refer-

Table 1: Data Rate and Rx Sensitivity in 802.11 OFDM PHY

Data Rate ν (Mbps)	Modulation Type	Coding	Rx Sensitivity P_{S_ν}(dBm)
06	BPSK	1/2	-82
09	BPSK	3/4	-81
12	QPSK	1/2	-79
18	QPSK	3/4	-77
24	16-QAM	1/2	-74
36	16-QAM	3/4	-70
48	64-QAM	1/2	-66
54	64-QAM	3/4	-65

ence distance $\overline{d}$ (normally, 1m) in dBm for signal speed of c and frequency f, and γ is the path loss exponent ($2 \leq \gamma \leq 6$) depending on the channel condition between T and R. From Eq. (1), let $P_r = P_{S_\nu}$ and $\overline{d} = 1$, we can determine the transmission range R_ν at rate ν as:

$$R_\nu = 10^{\frac{P_t - P_{S_\nu} - 20\log_{10}(4\pi f/c)}{10\gamma}} \tag{2}$$

The transmission range is used for calculating Link Weight as following:

Definition 1. (*Link Weight*) The Link Weight (w^ν_{jk}) at rate ν of the link from the j-th to the k-th is the ratio of the transmission range for the minimum data rate min(ν) to the transmission range for data rate ν.

$$w^\nu_{jk} = \frac{R_{\min(\nu)}}{R_\nu} = 10^{\frac{P_{S_\nu} - P_{S_{\min(\nu)}}}{10\gamma}} \tag{3}$$

It is obviously that the Link Weight ($w^\nu_{jk} > 1$) and R_ν will never be greater than $R_{\min(\nu)}$ because in this case the link will be broken because the two nodes out of communication range. Hence, the object is to find the best link with maximum link weight.

3.2 Modeling Connection Uncertainty of a Route

Consider a mobile ad hoc network with n nodes and let p^i_j is the probability that node j-th of the network stays at the i-th position in the route. Let l is the maximum number of links of possible routes from the source node s to the destination node d, so that in the worst case that there is only one route and all nodes participate in a route as a chain topology, we have (l=n-1). Since there are only (N=n-2) nodes (exclude two end nodes) compete to occupy the remaining position of total l links, and the probability distribution is complete for a legitimate route, the set of connection probability is satisfied:

$$\sum_{j \in N} p^i_j = 1, (2 \leq i \leq l) \tag{4}$$

The set of connection probability forms ($l \times n$) metric $\mathbb{P} = \left[p^i_j\right] \in \mathbb{R}^{l \times n}$. Note that for a legitimate route, since each node of the network cannot occupy more than one positions, the connection probability $\left(p^i_j\right)$ satisfies the condition $p^i_j p^r_j = 0$ ($1 \leq j \leq n$, for all $r \neq i$).

We can observe that the distribution function of connection probability $\left\{p^i_1, p^i_2, p^i_3, ..., p^i_n\right\}$ is variable, so that we can apply Shannon entropy [11] to calculate connection entropy of the MANET:

$$H(\mathbb{P}) = -\frac{1}{l-1}\sum_{i=2}^{l}\sum_{j=1}^{n} p^i_j \log_2 p^i_j \ (bits) \tag{5}$$

LEMMA 1. *The connection entropy $H(\mathbb{P})$ has the values lying on the following condition: $0 \leq H(\mathbb{P}) \leq \log_2 n$.*

PROOF. First, as the definition of information entropy $H(\mathbb{P}) = E_{\mathbb{P}}\log_2\frac{1}{\mathbb{P}}$, and obviously, $0 \leq p^i_j \leq 1$. So that $H(\mathbb{P}) \geq 0$. Next, using Jensen's inequality [4]: if f is a convex function and X is a random variable,

$$Ef(X) \geq f(EX) \tag{6}$$

Moreover, if f is strictly convex, the equality in Eq. (6) implies that $X = EX$ with probability 1 (i.e., X is a constant). Apply to Eq. (5), we have

$$\begin{aligned} H(\mathbb{P}) &= \tfrac{1}{l-1} E\log_2 \sum_{i=2}^{l}\sum_{j=1}^{n} p^i_j \\ &\leq \tfrac{1}{l-1}\sum_{i=2}^{l}\log_2 E\left(\sum_{j=1}^{n} p^i_j\right) = \tfrac{(l-1)\log_2 n}{(l-1)} \end{aligned} \tag{7}$$

Hence, $0 \leq H(\mathbb{P}) \leq \log_2 n$ □

We can observe that if the values p^i_j of $\mathbb{P}$ are 0 or 1, the connection entropy is minimized and $H(\mathbb{P}) = H_{min} = 0$. In this case, $\left\{p^i_j\right\}$ defines the least uncertain route. $H(\mathbb{P})$ reaches its maximum value $H(\mathbb{P}) = H_{max} = \log_2 n$ iff $p^i_j = 1/n, \forall i, j$. In this condition, we have the most uncertain route that need to be avoid for selecting stable routes.

3.3 Associating Link Weight with Connection Uncertainty

For a link, we need to define its weight to choose the best route. Most of existing proposals do not give any detail how to calculate and assign a weight for communication link. In section 3.1, we have already proposed a comprehensive calculation of link weight. As discussed above, w_{jk} denotes the weight of the link from the j-th to the k-th node of the network. That link exists with probability of connection p^i_j. For a route, the weight associated with the i-th position is the sum of the link weight between the node that occupies the i-th position and the nodes occupying the previous and next positions in the route. Therefore, the weight associated with the i-th position can be calculated as:

$$W^i(\nu, \mathbb{P}) = \sum_{j=1}^{n}\sum_{k=1}^{n} p^{i-1}_j w^\nu_{jk} p^i_k + \sum_{j=1}^{n}\sum_{k=1}^{n} p^i_j w'^\nu_{jk} p^{i+1}_k \tag{8}$$

The average link weight for each position in the route can be defined as

$$\begin{aligned} W(\nu, \mathbb{P}) &= \tfrac{1}{l-1}\sum_{i=2}^{l} W^i(\nu, \mathbb{P}) \\ &= \tfrac{1}{l-1}\sum_{i=2}^{l}\left(\sum_{j=1}^{n}\sum_{k=1}^{n} p^{i-1}_j w^\nu_{jk} p^i_k + \sum_{j=1}^{n}\sum_{k=1}^{n} p^i_j w'^\nu_{jk} p^{i+1}_k\right) \end{aligned} \tag{9}$$

The proposed routing metric will use the average link weight as a factor to select the best route.

4. THE MULTI-RATE MANET ROUTING METRIC

In MANET environment, the connectivity among nodes always changes due to node mobility. A robust and stable routing protocol must be the protocol which is designed to deal with mobility problem. As mentioned above, in this paper, we modeling the mobility aspect based on its effect to data rate as well as node connectivity. For more detail, at the initial stage, suppose that p_j^i is the probability that node j-th of the network stays at the i-th position in the route. Also, depend on the position of that node with the nodes occupying the previous and next positions in the route, the corresponding link weight can be determined in the Eq. (8). When the node move close to or far away another node, the relative distance between two nodes has been changed. Consequently, the data rate can increase (in case the relative distance is shorter) up to the maximum supported rate (i.e., 54Mbps), or can decrease (in case the relative distance is longer) down to the minimum supported rate (i.e., 6Mbps). The connectivity is broken when $R_\nu > R_{\min(\nu)}$ (the two node out of communication range). Utilizing this relation, we actually transform the mobility aspect (traditionally based on node's velocity vector) into link weight which is variable following nodes' distance. Moreover, taking into account the stability of the network, we develop routing metric with the consideration of connection entropy $H(\mathbb{P})$. A route can be chosen if it has minimum connection uncertainty and maximum link weight. The minimum uncertainty of connection ensure the stability of the route, hence, reduce the probability of link brakeage and route reparation.

The multi-rate MANET routing metric therefore can be developed by determining the connection probability metric $\mathbb{P}$ and link weight that minimizes

$$M(\nu, \mathbb{P}) = \alpha H(\mathbb{P}) + \frac{(1-\alpha)}{W(\nu, \mathbb{P})} \quad (10)$$

under the constraint in Eq. (4)

$$\sum_{j \in N} p_j^i = 1, (2 \leq i \leq l)$$

subject to minimize $H(\mathbb{P})$ and maximize w_{jk}^{ν}

The routing metric in Eq. (10) is defined in terms of the weighted parameter $\alpha \in (0, 1)$. The weighted parameter determines the relative effect of the entropy and the link weight on the objective function $M(\nu, \mathbb{P})$. If $\alpha \to 0$, the effect of the entropy term in (10) is eliminated and the routing process is almost exclusively based on the maximization of the average link weight. As the value of α increases, the effect of the entropy term also increases and the maximization of the link weight $W(\nu, \mathbb{P})$ plays an increasingly dominant role. On the contrary, if $\alpha \to 1$, the entropy term is dominant and minimization of $M(\nu, \mathbb{P})$ implies minimization of the connection entropy $H(\mathbb{P})$.

The proposed routing metric requires cross layer support from the MAC for the computations of link weight. The MAC layer delivers received data packets to the network layer along with the *Received Signal Strength Indicator (RSSI)* for the packet. The RSSI provides information about receiver sensitivity P_{S_ν} from which the network layer computes the transmission range in Eq. (2) and the Link Weight following the Eq. (3).

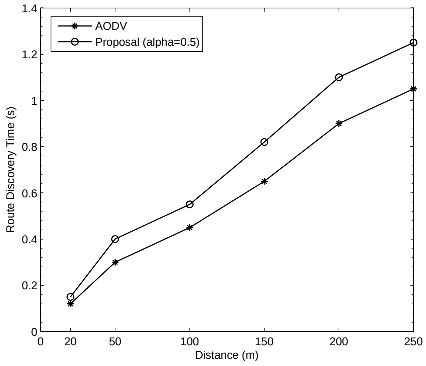

Figure 1: Route Discovery Time.

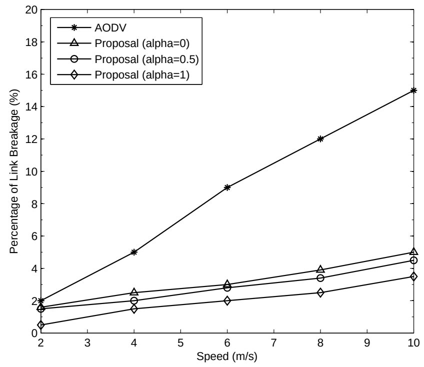

Figure 2: Percentage of Broken Link.

5. PERFORMANCE ANALYSIS

We evaluate the performance of proposed multi-rate routing metric using *NS-2* [1] to compare with traditional AODV protocol based on hop count metric. The network includes 100 nodes randomly distributed over a 250m x 250m area. The IEEE 802.11g standard is used. In a typical office environment, 802.11g's maximum range is about 100 feet (33 meters) at the lowest speed (6Mbps). Hence, this random topology ensures that nodes can use a specific data rate ν (ν = (0, 6, 9, 12, 18, 24, 36, 48, 54)Mbps). The Constant Bit Rate (CBR) traffic is randomly generated at several nodes in the network with packet size 1000 bytes. The random waypoint mobility model is used with maximum speed 10m/s. The path loss exponent (γ) value is normally in the range of 2 to 6 (where 2 is for propagation in free space, 6 is for relatively lossy environments). In this paper, we use $\gamma = 3$ to calculate transmission range R_ν following the Eq. 2. The performance metrics are obtained from the results of 50 simulation runs.

First, we observed the route discovery time and figured out that the proposed routing metric takes slightly longer time for average route discovery than AODV as show in the figure 1. In fact, the multi-rate MANET routing is designed

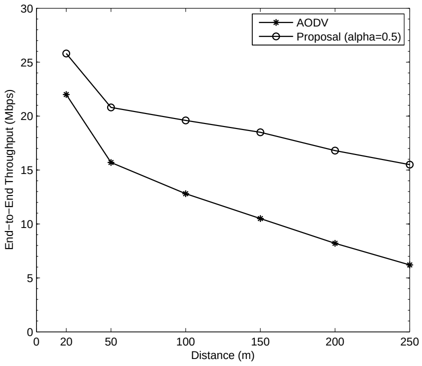

Figure 3: Average End-to-End Throughput.

to select the route with higher speed, hence, with the same distance from source to destination it may use more intermediate nodes than AODV with minimum hop count metric. This extra discovery delay commonly occurs for routing metrics which are not shortest path based, but in this paper the trade off is worthy for throughput improvement and route stabilization.

Second, for validating the robustness of route stabilization using the proposed routing metric, we observed the percentage of link breakage that causes route reparation and compare with that of traditional AODV. The figure 2 shows that in both case ($\alpha = 0, 0.5, 1$), the multi-rate metric sharply reduces the percentage of broken links. Even for the case $\alpha = 0$, that means the link weight is considered the most, the selected route is also more stable. The reason is the link weight $W^i(\nu, \mathbb{P})$ is also a function of connection probability metric $\mathbb{P}$ and it will select links with high connection probability values. Hence, the link weight once to be maximized, it can ensure the selection of stable links itself.

Finally, one of the most important factor of a routing protocol is end-to-end throughput. We performs our routing metric incase of $\alpha = 0.5$ (balance between link weight and stable route). The figure 3 shows that the throughput in both case downgrade when either the number of intermediate nodes increase or the distance between source and destination decrease. However, the proposed routing metric outperforms in both distances. Especially, when the distance increases, the throughput of AODV deducts much faster than that of our proposal. At the distance 200m, the proposed metric outperforms AOVD around two times (16.8 Mbps and 8.2 Mbps respectively) and at the distance 250m, it outperforms AOVD almost 2.5 times (15.5 Mbps and 6.2 Mbps respectively). This improvement is achieved because the proposed routing metric selects higher speed and more stable route than traditional AODV.

6. CONCLUSIONS

In this paper, we proposed a new routing metric for the multi-rate mobile ad hoc network. The proposal is motivated from the fact that routing metric in MANETs must use not only high speed but also more stable route. By modeling mobility aspect as the variation of the level of maximum data rate that connecting nodes can use when they move close to or far away from other nodes, we relate mobility problem with link weight and stability. Therefore, our new routing metric can reduce the probability of route reparation due to broken links and outperforms AODV in case of end-to-end throughput.

The proposed metric requires support from the lower layers to calculate link weight and use the appropriate transmission rate. Also, the route discovery time is slightly longer than minimum hop count metric. In the future, we will consider to apply new metric for multi-path MANETs routing. The multi-path can be use for route backup or simultaneously transmission. Also, more analysis will be performed to show the advantages of our proposal.

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