

A Multiple Path-Metrics Based Multi-path Routing Protocol for Providing Differentiated QoS to Various Data Traffic

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Abstract In this paper, we propose a novel multiple path-metrics based multi-path (MPMP) routing protocol, which can find the most suitable route that satisfies the requirements of various data traffic in mobile ad hoc networks (MANETs). In order to provide differentiated QoS to various traffic, we propose a weighted cost function based on multiple path metrics, and D-ETX (Data-driven ETX) and available bandwidth estimation methods. To our best knowledge, this work is the first attempt to consider the multiple metrics-based multi-path selections for providing differentiated QoS to various traffic in MANETs. Simulation results demonstrate that the proposed protocol can achieve a significant improvement in terms of packet delivery ratio and end-to-end delay over existing protocols.

1 Introduction

In this paper, we consider an MANET that carries multimedia traffic including streamed video and audio, which require differentiated QoS (Quality of Service). Multimedia streaming in MANET brings a lot of challenges [1, 2]. For example, multipath fading and shadowing effect may increase the variability of the link capacity and the transmission error rate.

In such a network, it is highly desired to find an appropriate route for ensuring the quality of multimedia streaming. However, most existing mobile ad hoc routing protocols focus on finding the minimum hop-count path [3]. Fewer works tried to

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find the best quality path in the presence of lossy links or congested paths. Even such studies have not paid attention for providing sufficient and differentiated QoS.

For example, single metric-based protocols treat all data traffic equally and focus on providing QoS with respect to throughput and delay [4, 5]. Therefore, single metric-based protocols may not satisfy the various requirements of different multimedia traffic.

A limited number of approaches considered multiple metrics [6, 7] as well as multiple paths [8, 9]. However, they do not offer various quality routes for differentiated services for different applications. In addition, most of those protocols considered route expiration time and energy consumption as key metrics for route selection. Those metrics may not reflect the QoS requirements of multimedia traffic.

In order to address the limitations of existing routing protocols and provide differentiated services for various applications, we propose a multiple path-metrics based multi-path (MPMP) routing protocol that uses a weighted cost function to select the most appropriate route according to the need of applications. We also propose D-ETX and available bandwidth estimation methods, which are incorporated with the weighted cost function to provide differentiated QoS.

In MPMP, the routing decision is made based on the traffic requirements since different applications require various types of QoS. For example, the data generation rate of video streams may be higher than best effort and voice traffic. Also, video transmissions need the minimum bandwidth to achieve a desired satisfactory level. On the other hand, voice streaming requires a more stringent deadline for delivery. Therefore, voice traffic demands the shortest reliable path. In addition, critical data needs higher reliability.

Our proposed protocol may choose the largest available bandwidth path for video traffic. For voice traffic, it may select the shortest reliable path. Highest reliable path is chosen for critical data by selecting a path with the lowest D-ETX. In other words, multiple paths based on different demands can provide an appropriate route to each of the data traffic i.e., the same source and destination pair may have multiple different paths for each data traffic.

Extensive simulations have been performed, and the results show that our proposed protocol can outperform existing ad hoc routing protocols in terms of packet delivery ratio and average packet delay.

The rest of this paper is organized as follows. In Sect. 2, we present MPMP routing protocol design in detail. Section 3 presents the performance study. Section 4 concludes the paper.

2 MPMP Routing Protocol

In our protocol architecture, the cost of a path is estimated by considering multiple path-metrics. A weighted cost function is used to determine the multiple routes from the source to the destination node according to data traffic requirements.

2.1 Cost Function Design Based on Multiple Path-Metrics

This sub-section describes the design of the weighted cost function. The objective of the function is to estimate the cost for each path using various path-metrics. In this paper, we consider three important metrics which are bottleneck bandwidth, the data-driven expected transmission count (D-ETX) and the end-to-end path length.

First, the cost for each metric is estimated independently. Then, the overall cost of a path is obtained by using those individual costs for different metrics. Consideration of multiple metrics for a single route gives the opportunity of multiple quality paths. Since different data traffic may demand various kinds of service, multiple quality paths may provide an appropriate route to each of the data traffic. The overall cost of a path combines the different cost functions (or metrics) as a weighted sum. The overall cost of a route is calculated as follows:

$$C_i = \alpha f(x_i) + \beta g(y_i) + \gamma h(z_i) \quad (1)$$

where C_i represents the overall cost of path i , and $\alpha + \beta + \gamma = 1, 0 \leq \alpha, \beta, \gamma \leq 1$. Also, N is the set of available paths between the same source and destination pair.

Functions $f(x)$, $g(y)$ and $h(z)$ are the individual cost function for different metrics. Also, α , β and γ are weights of those functions, respectively. The cost functions are defined as follows:

$$f(x) = \frac{x_{\max} - x}{x_{\max}}, \quad 0 \leq x \leq x_{\max} \quad (2)$$

$$g(y) = \frac{y - y_{\min}}{y_{\max} - y_{\min}}, \quad y_{\min} \leq y \leq y_{\max} \quad (3)$$

$$h(z) = \frac{z - z_{\min}}{z_{\max} - z_{\min}}, \quad z_{\min} \leq z \leq z_{\max} \quad (4)$$

where x , y and z represent the bottleneck bandwidth, hop count and D-ETX of end-to-end path, respectively.

The values of α , β and γ are selected based on the data traffic requirements. Therefore, the same source and destination pair may have multiple different paths for each data traffic i.e., multiple paths can be used to carry data from the source node to the destination node.

The function $f(x)$ in (2) computes the cost of the path in terms of available bandwidth, whereas x_{\max} represents the maximum channel bandwidth. Note in (2) that, as the available bandwidth, x , increases, the bandwidth cost decreases i.e., higher the available bandwidth, lower the cost of the path.

Similarly, $g(y)$ in (3) estimates the cost using the end-to-end path length, y . The maximum length of a path, y_{\max} , is estimated based on our analytical observation, which is presented in Sect. 3. Note that (3) indicates that a shorter path length leads to a lower cost i.e., a better path. Similarly, function $h(z)$ calculates the cost of the

path using D-ETX. In this case, a lower D-ETX represents a lower cost of the path. Also note that all cost functions have the same scalar domain, which is $[0, 1]$.

We introduce a weight for each function in order to put a priority on particular metrics. The weight values are varied according to the traffic requirements. For example, the video data requires a high bandwidth. Therefore, it is desired that a path with a high bandwidth is chosen for video traffic. In other words, the weight value of α needs to be higher than β and γ when calculating the path cost using (1).

Similarly, the weight of β may need to be higher than α and γ for voice data. This is because the voice traffic needs a short and reliable path. Likewise, for critical data, γ may need to be higher than α and β . A high weight value of γ reduces the path cost in terms of D-ETX and increases the possibility of selecting a more reliable path.

2.2 D-ETX (Data-Driven ETX) Design

First, in order to observe the distribution of link loss ratio of an ad hoc network, we perform experiments to estimate the link loss ratio in terms of pair-wise packet delivery ratio. We use 802.11b in physical layer and CBR as data traffic in application layer.

Figure 1 shows the pair-wise packet delivery ratio of each link which has participated in data transmission. The distribution of link loss ratio shown in Fig. 1 gives us two important observations. First, a large number of links have a high loss ratio. These links might not be able to deliver data packet. Another observation is *Hello* packet and *ACK* packet can obtain a higher delivery ratio than data packets.

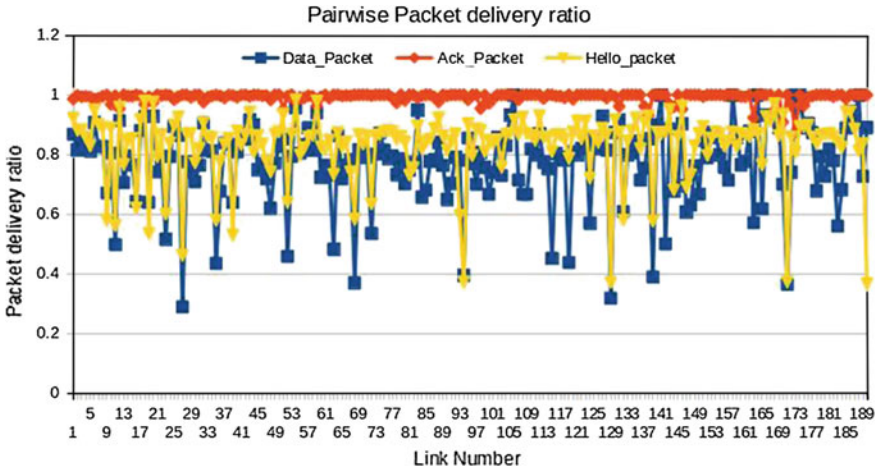


Fig. 1 Packet delivery ratio of Data, Hello and ACK packet

This indicates that *Hello* and *ACK* packet may not accurately reflect the real status of the link.

ETX represents the number of transmissions including retransmissions that is expected to deliver a packet. The original ETX [10] uses the forward and reverse delivery ratio which are calculated using the dedicated broadcast probe packets for each link. ETX of a routing path is the summation of ETX of each link of the route.

However, according to our observations discussed, the delivery ratio of probe packets may not correctly reflect the expected number of transmission or retransmission of a link since the broadcast probe packets are small in size comparing to multimedia data packet. Packet dropping probability of probe packet is very low. As a result, delivery ratio of probe packet can be high, even though the link is lossy.

Therefore, in our protocol, we propose the D-ETX calculation process for more accurate estimation. We consider the delivery ratio of actual data packet to estimate the D-ETX. We use the probe packets only when there is no data traffic over the link. Every node monitors the data traffic in the network and calculates the packet delivery ratio (d_{data}) of each link periodically.

$$d_{data}(t) = \frac{N_{ack}(t - T, t)}{N_{data}(t - T, t)} \quad (5)$$

where $N_{data}(t - T, t)$ and $N_{ack}(t - T, t)$ are the number of transmitted data packets and received acknowledgement packets at the node for last time window T , respectively.

Only when there is no data traffic of a link for a particular time, D-ETX is estimated based on the probe packet. In our protocol, we use *Hello* message as probe packet. Each host broadcasts a series of *Hello* packets during a fixed time window T and counted the number of packets sent and received. Suppose that every node broadcasts *Hello* packets of fixed size at every τ seconds. Then, the delivery ratio (d_{hello}) at time t becomes

$$d_{hello}(t) = \frac{N_{hello}(t - T, t)}{\frac{T}{\tau}} \quad (6)$$

where $N_{hello}(t - T, t)$ is the number of *Hello* packets received for last T seconds and T/τ is the number of probe packet it should receive.

Then, the data-driven expected number of transmission is calculated as

$$D - ETX = \frac{1}{d} \quad (7)$$

where d is the forward delivery ratio of the link based on type of packets i.e., d is set to $d_{data}(t)$ and $d_{hello}(t)$ of the forward link in cases of using data packets and *Hello* packets, respectively.

2.3 Available Bandwidth Estimation

In order to provide sufficient QoS for different traffic, a routing protocol needs to estimate the available bandwidth accurately. However, estimating the available bandwidth precisely using IEEE 802.11 MAC is a challenging task, since individual node has no knowledge about the status of neighboring nodes on carrying data traffic. Because the bandwidth is shared among the neighboring nodes under IEEE 802.11 DCF mode, estimating the consumed bandwidth of all nodes within the carrier sense range is necessary.

Therefore, we estimate the consumed bandwidth within the carrier sense range. Every node broadcasts its consumed bandwidth periodically using Hello messages i.e., the bandwidth usage of a host is piggybacked onto the Hello messages. We modify the AODV Hello message structure to include the consumed bandwidth information. Each node observes the total amount of data it fed into the network within a specific time window (e.g., 5 s).

The node can obtain the neighboring consumed bandwidth information through \$Hello\$ messages. However, node also needs to estimate the consumed bandwidth in its carrier sense range. Note that the interference range can be twice of the transmission range. Therefore, in this paper, we enhance the two-hop bandwidth estimation process [4] by taking into consideration the physical layer preamble and backoff time.

First, let BW_{av} , BW_{ch} and BW_{cn} denote the available bandwidth, channel bandwidth, and total consumed bandwidth, respectively. Then,

$$BW_{av} = \frac{BW_{ch} - BW_{cn}}{w} \quad (8)$$

where w is the weight factor and $w = (T_{overhead} + p)/p$ where p is packet size and $T_{overhead}$ is the overhead taken by routing protocol and MAC operations.

$$T_{overhead} = T_{PHY} + T_{MAC} + T_{UDP} + T_{IP} + DIFS + SIFS + T_{ACK} + T_{BCK} \quad (9)$$

where T_{PHY} , T_{MAC} , T_{UDP} , T_{IP} and T_{BCK} are physical layer preamble, MAC header, UDP header, IP header and average backoff time, respectively.

In order to more closely estimate the consumed bandwidth, the physical layer preamble and backoff time are also added for the weight factor. In this work, T_{BCK} is approximated by

$$T_{BCK} = \left(\frac{CW_{min}}{2} \right) T_{slot} \quad (10)$$

where CW_{min} represents the minimum contention window and T_{slot} is time slot. The available bandwidths of all hosts are estimated.

2.4 Best Route Selection Procedure

In MPMP, a modified route discovery mechanism of AODV is used to discover multiple paths between source and destination node. More specifically, when the source node has a packet to transmit and has no route to the destination, it initiates the route discovery by flooding route request (RREQ) messages. When an intermediate node receives an RREQ, it first updates the available bandwidth, D-ETX and the hop count in the RREQ header. When the destination node receives an RREQ, it first checks whether it is QoS traffic (e.g., video, voice and critical data). If the traffic requires QoS, the destination node stores the route in a temporary list and waits for the waiting period, which is the half of the route request time-out period. If the traffic does not require QoS, it just sends an RREP immediately to the source as in AODV.

After the waiting period, the destination node estimates the cost of each path using (1) and selects the lowest cost path according to the type of QoS traffic. Finally, destination node sends RREP to the source.

3 Performance Study

The proposed protocol (MPMP) is evaluated through simulation using NS2. We evaluate the performance of the protocol for video, voice and data traffic that require QoS. We assume a multi-hop wireless network of 50 nodes randomly distributed in 1000×1000 m area. IEEE 802.11 MAC protocol with RTS/CTS disabled is used. Note that RTS and CTS are used to alleviate the hidden terminal problem. However, for multimedia data transmissions it is recommended to disable RTS/CTS [11].

In our simulation, we consider 802.11b for physical layer which has the maximum channel data rate x_{max} of 11 Mbps. In this work, the H.264/MPEG-4 is used for video encoding, which supports a high video quality at a relatively low data rate due to a high compression ratio. We consider 25 frames per second where frame size of 480×360 with average background motion. By encoding the raw video data, the node load of video traffic becomes about 0.6048 Mbps.

For the best quality voice traffic, we use the G.711 encoding, which requires the data rate of 64 Kbps. From our observation, we notice that in a network of size 1000×1000 m with transmission range 250 m, the maximum number of hops (y_{max}) is about 5 on average. The maximum D-ETX of a link is about 2. Therefore, considering the worst case, the maximum D-ETX (z_{max}) of a path is set to $5 \times 2 = 10$ in this work.

In order to emulate the transmission of video, voice, and data, constant bit rate (CBR) traffic with data packets of 1500, 160, and 460 bytes is used on top of UDP, respectively.

Performance of the protocol is measured for different scenarios and topologies. In this paper, we present two sets (i.e., static and mobile network) of simulation results.

We use various number of QoS traffic connections over the static network and use various movement speeds over the mobile network. We compare MPMP with AODV, DSR, AODV with ETX, and Bandwidth Estimation-based QoS Routing Protocol (BEQRP) [5]. In the simulation scenario, we use video, voice, and critical data connections with node loads of 0.6048, 0.064 and 0.032 Mbps, respectively.

For simulations, different weight values for different traffic are considered. More specifically, for video, values of (α, β, γ) are set to (0.5, 0.3, 0.2), respectively. Also, value sets of (0.2, 0.5, 0.3) and (0.2, 0.3, 0.5) are used for voice and data, respectively.

3.1 Network with Stationary Nodes

We notice for video traffic that, initially the packet delivery ratio (PDR) of MPMP and AODV is close as shown in Fig. 2a. The reason is that initially network is not very loaded, and, as a result, all protocols show sufficient performance. As the number of connections increases, network load increases and PDR decreases for all protocols. MPMP shows a higher PDR in all the cases than AODV, DSR, ETX-AODV and BEQRP. This is because MPMP selects the highest bandwidth path with reliability which allows for avoiding the poor quality links and congested paths i.e., the highest bandwidth path can provide the required bandwidth and reduce the packet dropping probability.

MPMP also achieves PDR improvement for voice and data traffic comparing to other protocols as shown Fig. 2b, c. Note that, real-time characteristics of voice traffic make it delay sensitive, which requires to meet the deadline. By considering the requirements of voice traffic, MPMP selects the shortest path with reliability and bandwidth. Since MPMP can avoid the lossy and congested path by using D-ETX metric for data traffic, a low number of route breaks occurred compared to other protocols.

In terms of delay, as shown in Fig. 3a, MPMP shows a better performance than AODV, ETX-AODV and BEQRP which is essential for real-time video traffic. Note that AODV, DSR, and ETX-AODV determine a route without considering the

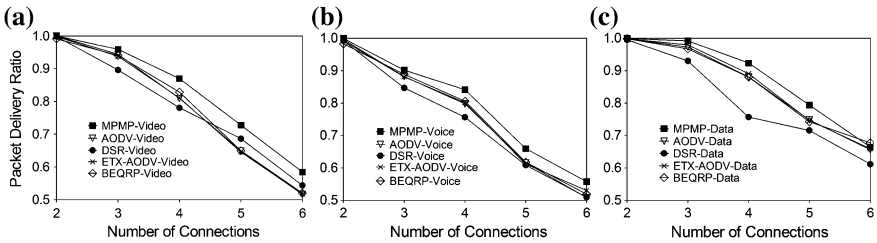


Fig. 2 Effects of variable traffic connection on packet delivery ratio. **a** Video traffic. **b** Voice traffic. **c** Data traffic

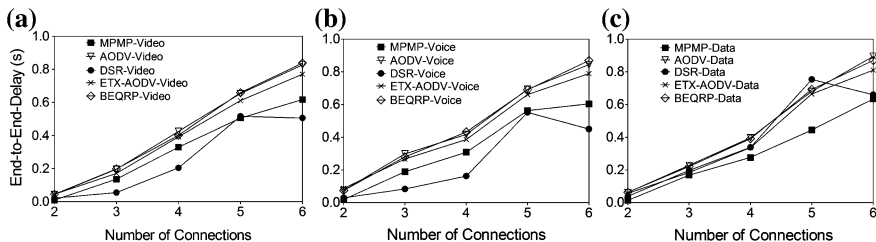


Fig. 3 Effects of variable traffic connection on end-to-end delay. **a.** Video traffic. **b.** Voice traffic. **c.** Data traffic

bottleneck bandwidth and congestion in the network. When the route is highly congested, packet needs to wait for a long time in the queue in AODV, and ETX-AODV. Note that DSR achieves the lowest delay for video and voice traffic, as shown in Fig. 3a, b at a cost of a very low throughput shown in Fig. 2a, b, which may make it impractical.

As shown in Fig. 3c, MPMP shows the lowest delay for data traffic, even though the protocol puts a priority on reliability. This is because a reliable path can also have a lower delay due to less packet retransmissions and re-discovery of routes.

3.2 Network with Mobile Nodes

We use the random waypoint model (RWP) to simulate the movements of nodes. The node speed is randomly chosen in $(0, v_{max})$, where v_{max} is maximum node speed. We collect performance results of protocols over variation of the node speed while keeping the same number of data connections. Specifically, we use 2, 5, and 5 connections for video, voice and data traffic, respectively.

As shown in Fig. 4, MPMP gains a high PDR compared to other protocols. Figure 4b shows the PDR of voice traffic. In this case, MPMP obtains the highest performance in all cases. Note that MPMP selects a path that has the shortest path

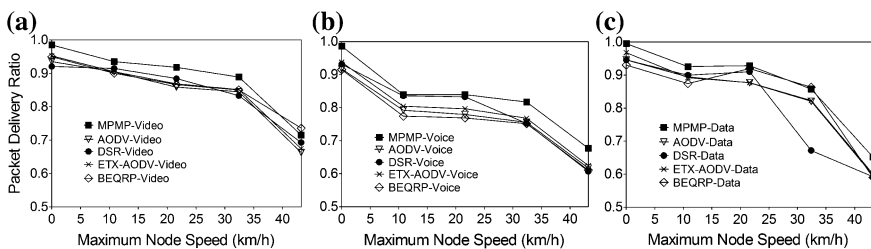


Fig. 4 Effects of variable node speed on packet delivery ratio. **a** Video traffic. **b** Voice traffic. **c.** Data traffic

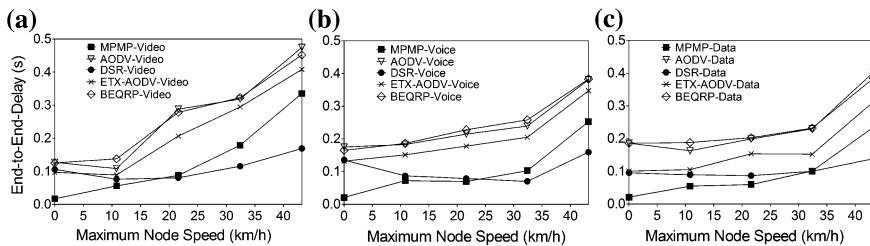


Fig. 5 Effects of variable node speed on end-to-end delay. **a** Video traffic. **b** Voice traffic. **c**. Data traffic

length and reliability. AODV, ETX-AODV and BEQRP show similar trends in all cases. The PDR values of data are shown in Fig. 4c. The PDR decreases while the node speed increases. However, MPMP protocol shows a better performance. This is because a lower number of route break occurred in MPMP.

In terms of delay, as shown in Fig. 5a, the frequent route break due to node mobility causes extra delay for each protocol. MPMP gains a low delay comparing to AODV, ETX-AODV and BEQRP. As shown in Fig. 5b, MPMP can achieve a low delay comparing to others protocols. AODV and BEQRP show the highest delay. For data traffic, as shown in Fig. 5c, the delay of AODV, ETX-AODV and BEQRP is high comparing to MPMP. This is because route break in AODV, BEQRP and also in ETX-AODV is more frequent.

4 Concluding Remarks

In this paper, we have proposed a novel multiple path-metrics based multi-path (MPMP) routing protocol for providing the best suitable route according to QoS requirements of applications. A new weighted cost function has been designed to determine the cost of a routing path based on enhanced bandwidth estimation, D-ETX and end-to-end length of the path. Simulation results show that the proposed protocol can outperform existing routing protocols in terms of packet delivery ratio and end-to-end delay.

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