Multipath QoS Routing for Mobile Ad Hoc Networks

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Abstract - Recently, quality-of-service routing in dynamic, wireless multi-hop ad hoc networks becomes a hot research topic, and various QoS protocols are proposed Even so, popular QoS routing protocols rarely provide multiple routes. Once links break due to node mobility, establishment of new routes leads to large control overhead and more end-to-end delay. In MANETs to support multimedia applications such as video and voice require an efficient routing protocol and quality of service (QoS) mechanism. This paper presents a multipath QoS routing protocol for mobile ad hoc networks to support throughput and delay sensitive real-time applications in these networks.

A simple route stability model is utilized during both route discovery and maintenance phases for selecting QoS routes with higher stability. The reliability of the multiple QoS routes is improved through node disjointness and stability properties of the discovered routes. Extensive simulation studies show that the proposed routing protocol can support higher level of QoS in terms of packet delivery ratio, average end-to-end delay and jitter,.

Keywords - *Mobile ad hoc networks, Multipath routing, Route stability and Quality of service, Route stability-based multipath QoS routing (RSMQR).*

1. Introduction

Mobile Ad Hoc networks (MANETs) have been very attractive in tactical and military applications due to their self-configuring and self-organizing nature, and the capacity to promptly deploy without any wired base stations or infrastructure support. The rising popularity of multimedia applications and the potential commercial use of MANETs demand for wireless ad hoc networks to be able to carry diverse multimedia applications such as voice, video, and data. In order to provide quality delivery to real-time multimedia applications, it is imperative that MANETs provide quality of service (QoS) support in terms of throughput, delay, delay jitter, reliability, etc. [1,2]. QoS provision in MANETs is a challenging task, since in addition to obeying QoS constraints, one must consider the limitations of the network due to dynamic topology and a lower capacity shared wireless medium. On-demand routing protocols used for best-effort service in ad hoc networks should be adapted appropriately to meet the QoS requirements of the specific multimedia applications. A QoS routing protocol selects routes based on QoS metrics such as throughput, end-to- end delay, delay jitter, packet loss probability, etc. to satisfy specific requirements of the applications. AODV [3] protocol to provide QoS support with throughput and delay constraints.

Routing protocols used for QoS support in MANETs are mostly based on on-demand unipath routing protocols due to their relative advantages as compared to the proactive routing protocols. But, there is a basic limitation of using on-demand unipath QoS routing protocols which is as follows. When an active route fails, due to either link failures or QoS violations, these on-demand protocols have to invoke a route discovery to recover from route failure. In a dynamic environment, the frequent route failures cause the nodes on the failed routes to drop packets due to unavailability of alternate paths. Further, the route recoveries are very expensive in MANETs because it results in extra control overhead due to flooding of routing packets. This results in high end-to-end delay and lower throughput for the affected applications. Using a QoS-aware multipath routing, a number of QoS-aware alternate paths can be made available at the source (based on some selection criteria) with a single route discovery. Then, out of the number of alternate paths discovered, one can be designated as the primary path and the others as secondary paths (based on some stability criteria on these discovered paths). In such multipath protocols, if a link failure or a QoS violation is detected on the primary path (through which actual data transmission is taking place), the source can switch to an alternate path instead of initiating a route discovery/recovery process. A new discovery takes place only when all precomputed paths break. This results in reduction in end-to-end delay and packet loss for the affected flows, since packets do not need to be buffered for long time at the source when an alternate path is available.

The rest of the paper is organized as follows: Section 2 gives an overview of the related work. The proposed Route stability-based multipath QoS routing (RSMQR) are presented in sections 3. The performance of RSMQR is evaluated and compared with AOMDV [5] in section 4. Finally, section 5 concludes the paper.

2. Related Works

In standard on-demand routing protocols (like AODV and DSR), when an active route breaks, the nodes of the broken route simply drop the data packets because no alternate route to the destination is available. Some local route maintenance schemes were proposed in [6-8] to reduce the route recovery cost in on-demand protocols. Some local route maintenance schemes were proposed in [6-8] to reduce the route recovery cost in on-demand protocols. The proposal in [7] proposed an optimization of the AODV-BR. In this approach [7], instead of using only the overheard RREP packets to learn backup paths, it used both RREP and data packets to increase the possibility of learning more backup routes. Backup routes may solve the route failure problem temporarily and is not effective in QoS-aware data transmission. In [8], to recover from a broken path, the source uses a limited route request flooding within a few hops around the broken path. The route recovery using the localized flooding is not a promising solution especially in a highly mobile environment because applications require QoS guarantee on an end-to-end basis. Multiple routes provided by multipath routing can be used to compensate for the dynamic topology changes in MANETs.

Earlier works on multipath routing [5, 9-12] show that providing more than one path can better support the high-mobility network with low end-to-end delay, high packet delivery ratio, and lower control overhead. All these protocols are designed to work for enhancing service to best-effort traffic. QoS-aware multipath routing protocols proposed in [13, 14] are based on a CDMA/TDMA-based MAC layer. Due to difficulty in realizing such centralized MAC scheme in MANETs, we consider only multipath routing based on a distributed MAC layer such as IEEE 802.11 DCF. In QDMR [17], a QoS framework is proposed to support delay-sensitive real-time applications in MANETs. It consists of two parts: (i) a reliable and QoS-aware routing through disjoint paths discovery and maintenance, and (ii) providing differentiated service to real-time and best-effort traffic through DiffServ.

IMRP [23] proposes an interfering-aware QoS multipath routing protocol for multimedia applications in ad hoc wireless networks. The protocol in [11] combines NDMR [20] with DiffServ for supporting QoS in MANETs. To improve QoS performance of DiffServ, NDMR helps in reducing routing overhead and controlling congestion through load balancing over multiple node-disjoint paths. Finally, in all multipath routing protocols found in the literature, a reasonable amount of path diminution problem [4] exists. The main reasons are the RREQ forwarding policy and the path selection procedure adopted at the intermediate nodes and the destination, respectively. Nasipuri *et al*. showed in their paper [21] that performance gain is marginal beyond a few number of paths. Our objective in this paper is to design a multipath protocol to support QoS in MANETs, which selects a maximum of three QoS-aware paths. Further, to increase the reliability of the discovered paths, we consider node-disjoint paths with higher route stability values.

3. Route Stability-based Multipath QoS Routing Protocol

Route stability-based multipath QoS routing (RSMQR), uses a new QoS parameter called *route stability* along with *throughput* and *delay*. RSMQR uses the route stability model for computing route stability. Route request/reply packets of the routing protocol help in selecting routes with higher stability among all the feasible paths between a given source destination pair. RSMQR computes a maximum of three node-disjoint QoS routes from the source to the destination and uses the route with maximum route stability as the primary path and the others as the secondary paths.

Figure 1 shows two types of disjoint paths between nodes *S* and *D*, where Figure 1a is for node-disjoint paths and Figure 1b is for link-disjoint paths. It is easy to show that the number of node- disjoint or link-disjoint paths between a given pair of source and destination is bounded by the number of one-hop neighbors of the source and the destination. Our protocol computes node-disjoint paths to increase the likelihood that when the primary path breaks due to node movement or QoS violation. Further, preferring routes with higher stability improve the reliability of the discovered paths. Previous studies [5,9,12] show that such node-disjoint paths typically fail independently.

The possible number of completely node-disjoint paths with QoS constraints at a moderate node densities is very limited [9] and performance improvement due to an increase in the number of disjoint paths beyond two or three paths is very marginal [21]. In RSMQR, a periodic maintenance and validation of the alternate paths is performed which results in switching of primary route to an alternate route, if the stability value of the alternate route is higher than that of the primary route. A new route discovery is initiated only when all the paths in the multi path fail.

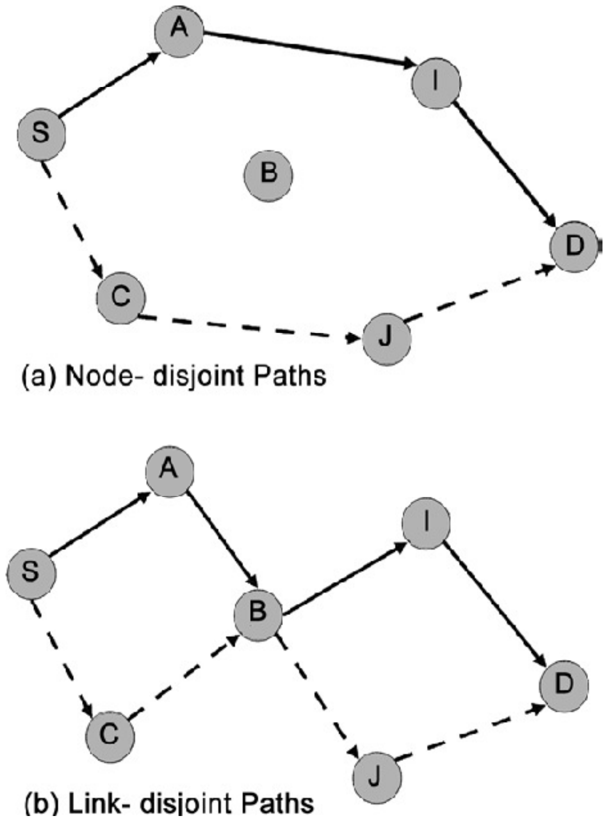

Fig. **1** An example showing disjoint paths between *S* and *D*.

Our route discovery procedure adopts the following policies: (i) selective forwarding of duplicate route request message is adopted to maximize the possibility of tracing all the feasible disjoint paths from the source to the destination and (ii) all route request messages received by the destination will carry complete path information from the source to the destination (like in DSR). It helps the destination to compute a set of node-disjoint paths by processing path information. The policies adopted are particularly important in a QoS aware routing due to the limitation of number of feasible paths in the network.

We propose an on-demand distributed routing algorithm where all the nodes contain only information about their one-hop neighbors. The following network model assumptions are made:

• Neighborhood is a commutative property, i.e., if node A can hear node B, this implies that node B also hears node A

• CSMA/CA like MAC protocol is used for reliable unicast communication and it solves the hidden terminal problem with the help of RTS-CTS control packets

• There is a close interaction between the MAC layer and the network layer

• Combinatorial stability of a network is assumed; it means topology changes occur sufficiently slowly to allow successful propagation of all topology updates as necessary

• Hello intervals to update neighbor information is reasonable to capture the dynamics of the network

• Transmission range and carrier sensing range are assumed to be same for available band width calculation at a node

• Initial route discovery latency is tolerable in the supported applications

3.1 Delay and Bandwidth Estimation

We measure the per hop delay by using the MAC delay at a node which is cross-layer information. A node computes the MAC delay (*d*) by subtracting the time (*ts*) that a packet is passed to the MAC layer from the time (*tr*) an ACK packet is received from the receiver for the same packet. In order to minimize the biasness against transient changes in the delay, an exponentially weighted moving average (EWMA) estimator is used to measure the average of the MAC delay (d_{avg}^{i}) as shown in Equation (1). Here, d^{i} and d_{avg}^{i-1} are the measured MAC delay and the previously stored average MAC delay, respectively, in a node. η is a positive constant, and in our experiment we set it as 0.4.

$$d_{avg}^{i} = \eta \text{ x } d_{avg}^{i-1} + (1-\eta) \text{ x } d^{i} \qquad (1)$$

4. Simulation and Performance Evaluation

In this section, we evaluate the QoS performance of the RSMQR protocol through an extensive set of simulations, under various mobility conditions. For comparison purpose, we consider the node-disjoint version of the AOMDV [5] which is a widely accepted standard for multipath routing in MANETs. We take AOMDV [5] for performance comparison with RSMQR, because AOMDV is the closest protocol to RSMQR compared with other multipath protocols (both QoS-aware and without QoS) found in the literature. QoS-aware multipath protocols found in [13, 14] are based on CDMA/TDMA-based MAC protocols, and therefore, they are excluded for performance comparison with RSMQR. The multipath protocol proposed in MP-DSR [15] considers only reliability of packet delivery as the application's QoS requirement without delay and throughput parameters. Therefore, it is not compatible with RSMQR. ADQR [16] is based on the simultaneous use of the multiple disjoint paths to support application's throughput requirement and hence is not compatible with RSMQR. Similarly, proposals in [11, 17] use the DiffServ model for service differentiation and are therefore not compatible with RSMQR.

4.1. Performance Metrics and Simulation Parameters

Following metrics have been used for performance analysis:

• Packet delivery ratio (PDR): This is the ratio of the number of data packets received at the destinations and the number of data packets actually sent to the network. This measures the quality of the discovered path.

• Normalized control overhead (NCO): This is the ratio of the number of control packets sent to the network hop-wise and the number of data packets delivered at the destinations. This measures the overhead induced by the protocol.

• End-to-end delay (E2ED): This gives the average time delay that a data packet has encountered from the time it was sent by a source to the time it was delivered at the destination. This measures the delay performance of the QoS flows.

• Maximum jitter (MJ): This gives the maximum variations in the delay among the delivered data packets at the destinations.

• Dropped packets (DP): This gives the total number of data packets dropped during communication in the network.

To evaluate the performance of the RSMQR protocol and perform the comparative study with AOMDV [5] under different mobility and network load conditions, an extensive simulation is performed using NS-2 [22]. For each type of scenario, we run the simulation for 10 times (with random scenarios with different seeds) to take average values in the measured performance metrics. The connection pattern consists of 10 flows (for high-load 15 flows) between randomly chosen source-destination pairs among the 50 nodes. The QoS flow taken is CBR with a packet size 512 bytes at a rate of 10 packets per second. All the generated flows have same QoS requirements. The detailed simulation parameters are shown in Table 1.

Table 1: Simulation parameters:

Parameter name	Value
Topology	1000 X 500 flat-grid area
Mobility model	Random waypoint
Pause time (s)	0
Packet size (B)	512
No. of nodes	50
Simulation time (s)	500
Maximum node speed (m/s)	0, 5, 10, 15, 20

5. Result Analysis

To evaluate the performance of the RSMQR protocol and perform the comparative study with AOMDV [5] under different mobility and network load conditions, an extensive simulation is performed using NS-2 [22]. For each type of scenario, we run the simulation for 10 times (with random scenarios with different seeds) to take average values in the measured performance metrics. The connection pattern consists of 10 flows (for high-load 15 flows) between randomly chosen source-destination pairs among the 50 nodes. The QoS flow taken is CBR with a packet size 512 bytes at a rate of 10 packets per second.

From figures 2 and 3, we can observe that the packet delivery ratio (PDR) of RSMQR improves significantly in comparison with the AOMDV protocol. For 10 flows, the PDR of RSMQR is more than 97% in all mobility cases whereas the PDR of AOMDV reduces up to 82%. Similarly, RSMQR shows better performance for 15 flows with the minimum PDR at 94% at a 20 m/s mobility speed whereas the performance of AOMDV drastically changes to a minimum of 78% at the mobility speed of 20 m/s. This is mainly due to the following: (i) RSMQR always selects the most stable QoS path out of the selected node-disjoint paths for data transport; (ii) it performs admission control before admitting a flow in the network, thereby avoiding congested network paths.

Data packet loss during data communication sessions which are shown in figures 4 and 5, respectively. From these figures, the amount of data packet loss in AOMDV for 10 and 15 flow scenarios are more than two and three times, respectively, as compared to RSMQR. From figures 6 and 7, it can be observed that in all mobility scenarios of 10 and 15 flows, RSMQR maintains an average end-to-end delay below 10 ms which is less than the required maximum delay of 100ms. It is not possible to maintain the maximum delay bound for each and every data packet in a random access MAC protocol-based MANET. Though our protocol detects delay violation, it is not instantaneous. So, there will always be some number of packets which violate the delay requirements. Figures 8 and 9 show the maximum delay jitter for both RSMQR and AOMDV in all simulation scenarios.

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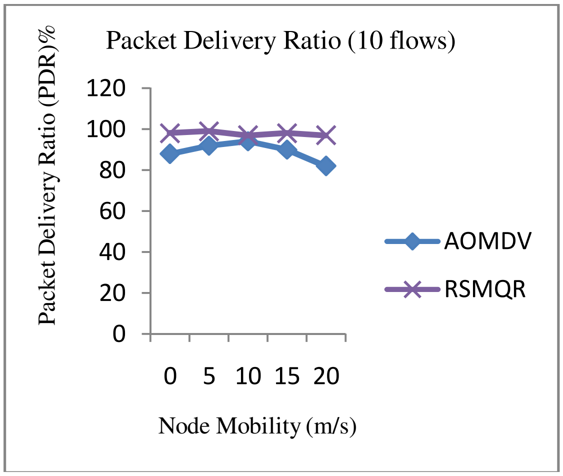

Fig.2

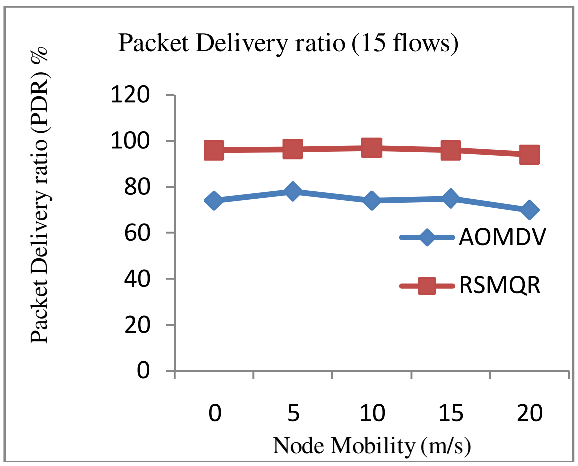

Fig.3

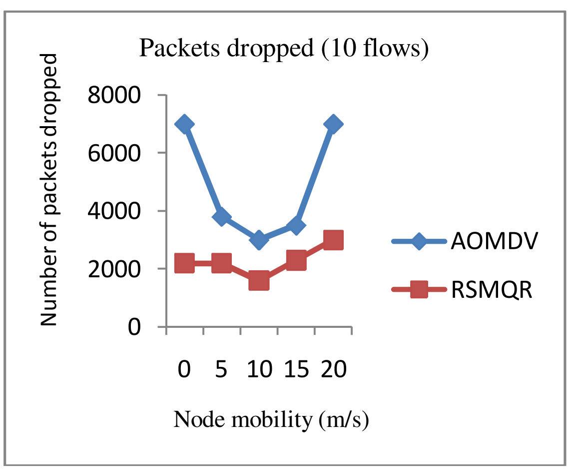

Fig.4

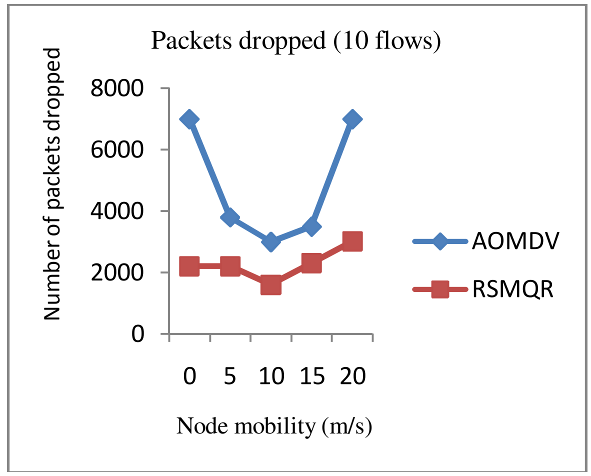

Fig.5

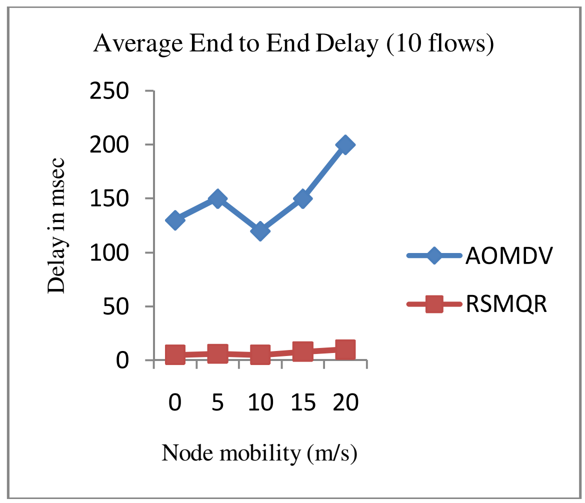

Fig.6

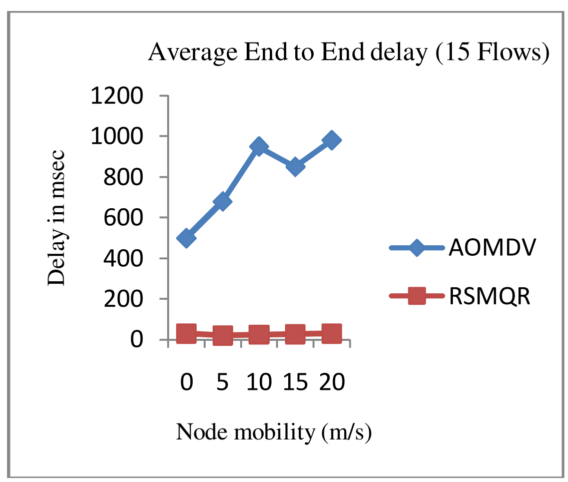

Fig.7

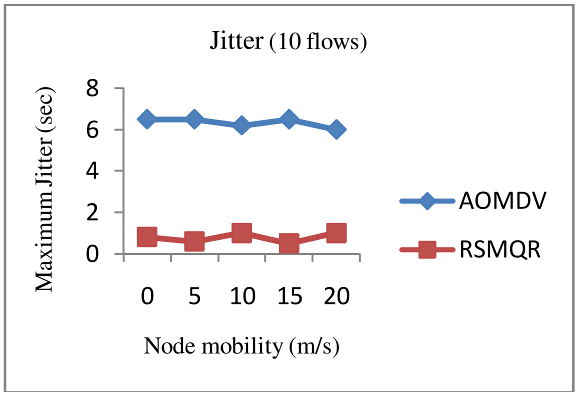

Fig.8

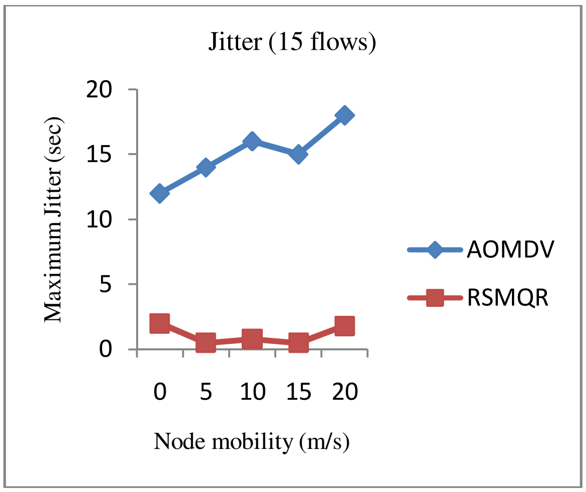

Fig.9

6. Conclusions

In this paper, RSMQR is proposed to provide QoS (delay and throughput) assurance to applications in MANETs. The use of a simple route stability model in the proposed multipath routing significantly reduces the number of route recoveries required during QoS data transmission. Simulation results show better performance of SMQR in terms of average end-to-end delay, packet delivery ratio, and maximum delay jitter.

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