A New Cross-Layer Framework for QoS Multicast Applications in Mobile Ad hoc Networks

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Summary

The need to support real-time and multimedia applications in mobile ad hoc networks (MANETs) has increased dramatically over the last few years. There are many challenges in supporting QoS for MANETs. The contribution of this paper is a new framework based on the cross-layer design and integration between a new routing protocol and other components that deal with different types of traffic. We propose a Framework for QoS Multicast (FQM) to support QoS multicast applications for MANETs that is able to support QoS enabled applications. The first component of the framework is a new and efficient routing protocol for finding multiple paths meeting the QoS requirements and for maintaining these paths. Second, cross-layer bandwidth estimation is used to estimate the available bandwidth and support it for other schemes. Third, classifier, shaper, dynamic rate control and priority queue work together to support high priority real-time traffic. We implemented a hybrid scheme that uses unipaths and redundant paths to share the available bandwidth for forwarding data packets. The performance of FQM was studied using the GLOMOSIM simulation environment. Analysis of the simulation results showed the ability of FQM to exploit the available bandwidth efficiently and provide a balance between performance gains and protocol complexity. The results indicated a high packet delivery ratio associated with low control overhead, low average latency and low jitter compared with QAMNet [1]. The FQM framework out-performed QAMNet in most experiments.

Key words:
MANET, QoS, classifier, shaper, dynamic rate control.

Introduction

Wireless networking and multimedia applications are rapidly growing in importance. Among various types of wireless networks, MANET provides flexible communication with low cost. In MANETs, all communications are done over wireless media without the help of wired base stations. The environment for MANETs is very volatile so connections can be dropped at any moment. Distant nodes communicate over multiple hops and nodes must cooperate with each other to provide routing. The challenges in MANET are attributed to mobility of intermediate nodes, absence of routing infrastructure, low bandwidth, and limited computational capacity. QoS routing in MANETs is difficult due to constantly changing network topologies.

The motivation for supporting QoS multicasting in MANET is due to the fact that Real Time (RT) multicast multimedia applications are becoming important for group communication. In addition to *RT* applications, users also request Best-Effort (BE) applications such as Email and File Transfer Protocol (FTP). In ad hoc communication systems, equal priority processing of RT and BE traffic result in poor performance of RT multimedia applications. *RT* applications have critical QoS requirements; whereas the packet delay and jitter are not big issues for *BE* applications [2]. This means that network needs to introduce service differentiation (RT and BE traffic) and support efficient QoS strategies to prevent *BE* traffic from affecting *RT* traffic.

The work in this paper focuses on one critical issue in future MANETs: QoS multicast support. The nature of the wireless channel requires that different layers (especially network and MAC layer) interact and integrate in order to optimize the limited and varying wireless network resources and provide QoS capabilities [3] [4] [5]. Reliable support for QoS in MANETs requires cooperation and interaction between the MAC layer and the network layer[6], enhancing system performance via a cross layer approach [7].

In this paper, we propose a cross-layer design using a new QoS multicast routing protocol to support QoS multicast applications in MANET. The routing protocol integrates multiple paths discovery with the search for paths with required bandwidth. The IEEE 802.11 MAC layer is enhanced to estimate the available bandwidth at each node. In addition, we introduce RT and BE priority mechanisms associated with many QoS schemes: namely *classifier*, *shaper*, *priority queue* and *dynamic rate control* modules.

Section 2 provides an overview of related work in QoS multicasting for MANETs. Section 3 describes the proposed framework (FQM) for QoS multicast applications. The performance of FQM and the comparison between FQM and QAMNet [1] is presented in Section 4. Finally, Section 5 summarizes the advantages of the FQM framework.

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2. Related Work

Multicast routing is more efficient in MANETs because the broadcast nature of RT communications that avoids duplicate packet transmission is inherently suited for multicast. Packets are only multiplexed when it is necessary to reach two or more destinations on disjoint paths. This advantage conserves bandwidth and network resources [8].

Several protocols have been developed to perform ad hoc multicast routing including CAMP [9] and ODMRP [10]. However, these protocols did not address QoS support. QoS multicast routing protocols should provide enabled QoS paths to all destinations, so they should cope with large number of paths and be able to utilize efficiently them. Each path from a source to one or more destinations is required to satisfy the specified set of QoS constraints [2]. QoS support multicast is provided by Lantern-trees [11] and QAMNet [1] approaches.

The lantern-tree protocol [11] uses a lantern-tree as a topology for multicast group and CDMA/TDMA for channel access at the MAC layer; however the lantern-tree require a long time at startup to find all sub-paths and to share time slots. Although multiple sub-paths have some advantages, i.e. path diversity may provide higher aggregate bandwidth through spatial reuse of the wireless spectrum, the use of a higher number of links creates more contention at the MAC layer, and the complexity for maintaining routes is higher [12].

The QAMNet approach [1] extends the existing On Demand Multicast Routing Protocol ODMRP [10] and the unicast QoS provisioning approach (supporting service differentiation for real-time and best-effort traffic in Stateless Wireless Ad hoc Networks - SWAN) [13]. QAMNet introduces service differentiation, distributed resource probing and admission control mechanisms to support QoS multicasting. The source node in QAMNet broadcasts a route request packet with the Bottleneck Bandwidth (BB) and Required Bandwidth (RB). When an intermediate node receives a route request packet, it rebroadcasts it after modifying the route request information. Each intermediate node updates the BB field if the local available bandwidth is less than the BB in the route request. Available bandwidth at the intermediate node is calculated similar to SWAN [13] where the threshold rate for *RT* flows is computed and the available bandwidth is estimated as the difference between the threshold rate and the current rate of *RT* traffic. It is very difficult to estimate the threshold rate accurately because the threshold rate may change dynamically depending on the traffic pattern [13].

When the route request arrives at destination, the destination evaluates the available bandwidth. If the BB is greater than the required bandwidth, it creates a route reply with the BB field. When the intermediate node receives the route reply it sets a RT forwarder flag (RTF_FLAG) for the given multicast group and rebroadcast the route reply. After the source receives the reply, it starts sending *RT* traffic. When the intermediate node receives the *RT* data packet it checks the flag (RTF_FLAG) and if the flag is set then it forwards the *RT* packet to the MAC layer directly; else the packet is sent to the shaper for BE traffic. QAMNet uses Additive Increase Multiplicative Decrease (AIMD) algorithm to regulate BE traffic based on the MAC layer back-off delay.

3. The Proposed Framework

Figure 1 gives an overview on all the components of the framework and describes the behavior of an intermediate node when it receives control or data packets coming from the other nodes. The QoS route request must enter into the admission control module and will be accepted or rejected based on the available bandwidth information. The traffic must be classified and processed based on its priority. Control packets and *RT* packets will bypass the shaper and is sent directly to the interface queue. *BE* packets must enter the shaper and will be regulated based on the dynamic rate control. In terms of queue priority, control packets have higher priority than *RT* packets and *RT* packets have higher priority than *BE* packets.

*3.1 QoS Multicast Routing Protocol**

We propose an on demand multicast routing protocol that uses forward nodes to apply multicast routing with QoS from source(s) to a group of destinations. The available bandwidth for any node changes dynamically as a result of node mobility; it is based on the number of neighbors for the node [14]. This protocol is a flexible hybrid scheme that combines some features from both IntServ and DiffServ First, the forward node provides IntServ to for every source for the QoS route request that has been accepted. Second, the forward node provides DiffServ when it receives data packets from other sources if it has extra bandwidth. At this point, usable bandwidth is partitioned into fixed-bandwidth for sources with route request entries, and shared-bandwidth for all other sources. Salient features of this protocol include efficient use of residual bandwidth, reduced control overhead by dropping route requests that were not accepted due to resource constraints and reduced redundant data transmissions by adopting the forward group scheme found in ODMRP[10]. The hybrid scheme switches between using redundant paths if the network has sufficient bandwidth for all sources and using unipaths similar to other multicast routing protocols if sufficient bandwidth were not available.

* A preliminary part of this work was presented at AINTEC 2005: the Asian Internet Engineering Conference (AINTEC), Bangkok, Thailand, 2005.

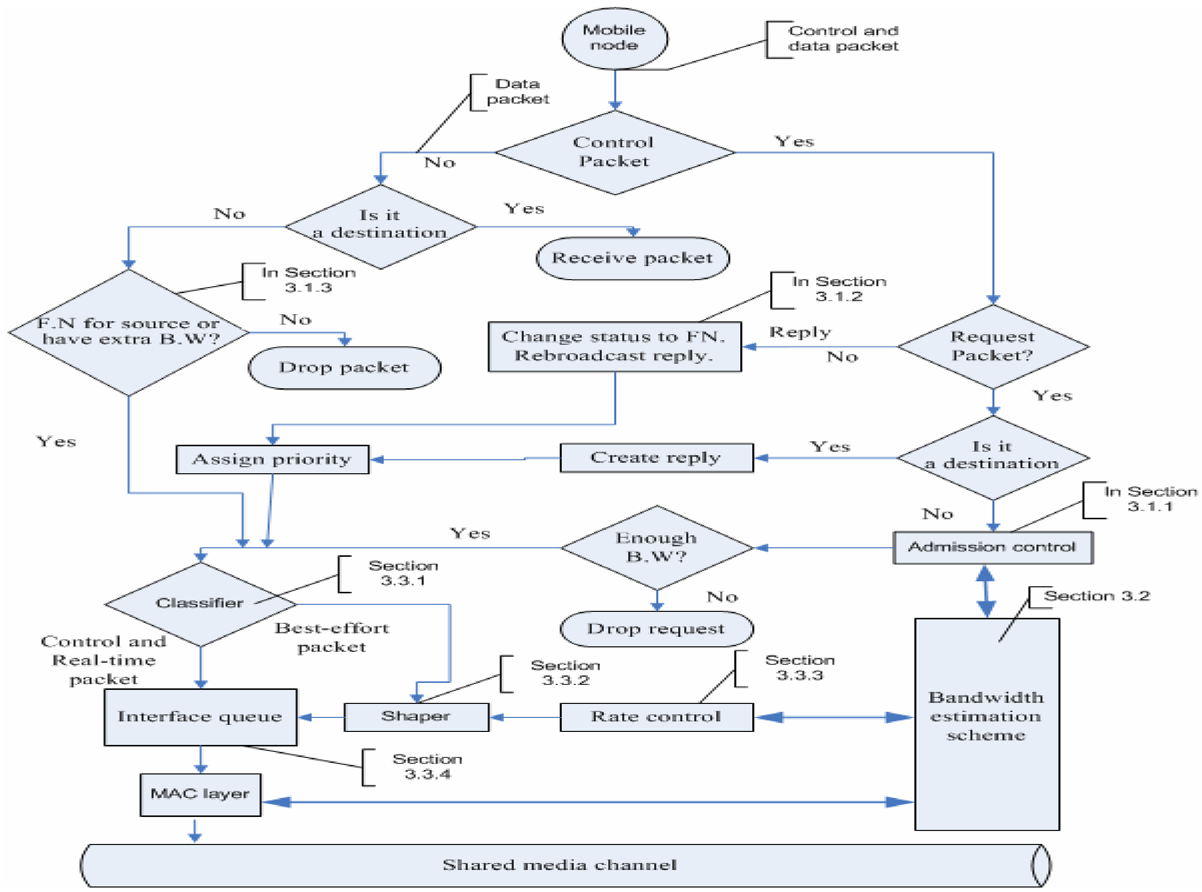

Figure 1: Functionalities of the cross-layer framework packet receiving flows

3.1.1 QoS Route Request and Admission Control

When a source node has data to send; it broadcasts a route request to search and discover paths to all destinations in the multicast group. When an intermediate node receives the route request, it records the source ID and the sequence number in its duplication table. Intermediate nodes rebroadcast the route request if three conditions are satisfied: the request is not a duplicate, the intermediate node has enough available bandwidth and the max-hop is greater than zero. The routing table is updated with the node ID in the route request for use as a reverse path to the source. The packet ID should be compared with those stored in the duplication table to prevent looping and receiving of multiple copies of the same route request. Finally, the route request reaches the destination if the path with the needed bandwidth exists. Admission control will use the information of the available bandwidth to determine if route request can be accepted. In the proposed protocol, when source updates forward nodes, the paths will also be updated. Intermediate nodes will then re-perform the admission control scheme for the request, so all changes caused by node movement will be taken into consideration.

In the proposed protocol, the request is accepted or rejected at each intermediate node; the packet that is dropped from this node may arrive at destination through other nodes witch have enough bandwidth; this provides the packet opportunity to arrive at destination through the nodes that have enough bandwidth and this balances the load on intermediate nodes. Also it saves bandwidth by not forwarding requests that will be dropped at the destination. In contrast, the QAMNet protocol accepts or rejects the request only at destinations. The forward node will continue to forward QoS route requests even when there is not enough available bandwidth and these requests will be dropped at destinations.

3.1.2 Reply Phase and Forward Nodes Selection

Initially, a multicast destination initiates the reply phase by choosing the next hop to the source and sending the reply. When an intermediate node receives the reply it checks if the next hop ID in the reply matches its own ID. If it does, the node realizes that it is on the reverse path to the source and it is one of the forwarding nodes, so it sets the forward node flag. The intermediate node extracts the information of the next hop node ID and fills it in the reply field. In this way, each intermediate node propagates the route reply until it reaches the multicast source. An acknowledgment packet is used to guarantee reply arrival. This whole process constructs the Forward Nodes that forward data packets from source to destinations.

3.1.3 Data Forwarding and Route Recovery

Here we consider how data is transmitted through the Forward Nodes. When an intermediate node receives a data packet, it passes the packet to the traffic classifier if it is a Forward Node for the packet source or if there is enough residual bandwidth.

To continue forwarding data packets, the paths from source to destination should be refreshed. In the proposed protocol, we use source advertising instead of destination advertising; each source periodically sends route request that apply route recovery by updating forward nodes, similar to the scheme used in ODMRP[10]. The value of the interval for sending route requests is very important. Several tests were carried out to determine this value, and five seconds was chosen as the interval for sending routes requests since it provides the best tradeoff between throughput and overhead. In the proposed protocol, source and destination nodes use soft state for leaving; source and destination nodes can leave session by stopping the periodic transmission of route requests and route replies respectively.

3.2 Bandwidth Estimation

QoS multicast routing needs an efficient way to estimate the available bandwidth and use it to perform accurate admission control. Contention-free schemes (CDMA and TDMA) are more applicable to static and centralized networks and is assumed to be used where topologies do not change very fast [15]; it is difficult to realize such centralized MAC modes in a dynamic wireless environment, which generally use the IEEE 802.11 protocol [16]. Estimating available bandwidth using the IEEE 802.11 MAC in MANETs is still a challenging problem, because the bandwidth is shared among neighboring hosts. The schemes for estimating available bandwidth need to take into account the activities of the nodes neighbors. The passive listening method was used to estimate the available bandwidth based on the radio channel status; it computes the idle periods of the shared wireless media. Any send or receive activity from other nodes will affect the channel status. Each node listens to the channel to determine the channel status and computes the idle duration for a period of time t. The IEEE 802.11 MAC utilizes both a physical carrier sense and a virtual carrier sense. Since multicast transmission does not use virtual carrier sense (RTS/CTS), we rely on physical carrier sense to determine the idle and busy state of the channel and determine the channel activity. In this case, the IEEE 802.11 wireless radio has two states:

- Busy state (transmit, receive, carrier sense)
- Idle state

Each node will constantly monitor when the channel state changes; it starts counting when the channel state changes from Busy state (transmit, receive, carrier sense) to Idle states and stops counting when channel state changes from Idle to Busy state. The idle time is composed of several idle periods during an observation interval t; the node adds up all the idle periods to compute the total idle time. We divide the idle time by the observation interval t to calculate the Idle Ratio and multiply it with the raw channel bandwidth (2Mbps for standard IEEE 802.11 radio) to find the available bandwidth. The bandwidth is continually estimated for every period t. The passive listening method is straightforward and relatively accurate with no control overhead where active hello messages are more accurate but has the disadvantage of very high control overheads; this control overhead increases with the number of nodes [17]. In our case, limiting overheads is a higher priority, so the passive listening method is used to estimate available bandwidth. The approach described in this section addresses the challenge of finding a good trade-off between efficiently estimating available bandwidth and reducing the associated control overhead.

3.3 Distributed Controls

To support *RT* applications, the traffic should be classified into *RT* and *BE* traffic. A shaper must be used to regulate the *BE* traffic rate. In this Section the traffic *classifier*, traffic *shaper*, *dynamic rate control* and *priority queue* used at each intermediate node to classify and control the traffic rate are described in grater details.

3.3.1 Traffic Classifier

The applications proposed for *RT* are very sensitive to packet delay and jitter whereas the packet delay and jitter are not critical for *BE* applications. We use the packet classifier to identify the packets of incoming traffic. To realize effective traffic control, each incoming data packet is mapped to one of two classes (*RT* and *BE* traffic). The choice of the class is based on the Type of Service (ToS) field in the IP-header that has to be enabled for each packet field.

3.3.2 Traffic Shaper

When a Forward Node receives a packet, the classifier decides which type an incoming packet belongs to. If the packet is a *RT* packet or a control packet, it enjoys precedence and is processed as soon as possible. Otherwise, the packet is considered low-priority and must normally wait to the forward depending on the rate control. The *shaper* limits the relaying of *BE* traffic to reduce contention between neighboring nodes, support enough available bandwidth for *RT* traffic and keep the delay of *RT* traffic as low as possible. This occurs in a distributed fashion since there is no centralized node. Therefore each node is performs its own traffic shaping without being aware of the traffic on other nodes. *BE* traffic can affect *RT* traffic due to the 802.11 DCF contention mechanism.

Intermediate nodes wishing to send high priority data might have to wait too long to acquire the channel and cannot transmit their control packet or *RT* packet (high-priority) in time.

3.3.3 Dynamic Rate Control

The need for dynamic rate control arises in MANETs due to dynamic topology changes that may affect the available bandwidth and cause quality degradation to ongoing communication sessions. To overcome this, each node needs to check available bandwidth periodically and change the rate control value based on available bandwidth.

We use dynamic rate control based on Additive Increase Multiplicative Decrease (AIMD) algorithm at each intermediate node to regulate the *BE* traffic rate independently. QAMNet uses the back-off delay of 802.11 as feedback to regulate the shaping rate of the *BE* traffic; whereas, FQM regulates the *BE* traffic rate based on available bandwidth. The *BE* traffic can be rate-controlled locally and rapidly in a distributed manner to achieve low delays and stable throughput for *RT* traffic. The traffic rate controller controls the traffic shaper output rate using an AIMD rate control algorithm. The traffic rate is decreased if the available bandwidth decreases; otherwise, the traffic rate is increased. As a result of using the passive listen method to estimate the available bandwidth, each node takes into account the activities of its neighbor nodes; during this time all neighbors of the Forward Node will reduce the injection of *BE* traffic into affect network. After the control rate module reduces the injection of *BE* traffic, the FQM scheduling algorithm will process high priority control packets and RT first before processing the BE packets.

3.3.4 Queuing Management and Packet Scheduler

Scheduling algorithms play an important role in the cross-layer framework. The service differentiation should be completed in the packet queue(s) through queue management. The framework should take into account the time urgency of different applications and schedules the packets based on their priority. For an on-demand routing protocol, experiencing frequent topology changes the ability to deliver control (routing) packets quickly is important for quickly discovering and maintaining the routes.

The performance of priority queuing in mobile ad hoc networks was studied in [18]. The aim of queue management is to schedule the different priority packets. To efficiently offer the service differentiation in a distributed ad hoc network, the packet with high priority should be granted higher priority for sending the channel. Control packets should have the highest priority, while RT packets should have higher priority than BE packets. RT packets will be sent to the channel a head of BE packets, reducing delay of RT applications and improving the packet delivery ratio. The interface queue consists of three sub queues with different priority (control, RT, BE) and every packet is classified into one of the three categories. Packets are de-queued from a higher priority queue before those from lower priority queue. The drop tail policy is used in all queue priorities. The drop tail policy drops all arriving packets to a queue when the queue is full.

4. Performance Evaluation

We have conducted experiments using GLOMOSIM [19] to evaluate the effectiveness of the proposed cross-layer framework FQM. The main concern of these experiments is to evaluate the proposed cross-layer framework for supporting QoS multicast applications and compare it with QAMNet. QAMNet is an existing approach for supporting *RT* and *BE* applications. This simulation was run using a MANET with 100 nodes moving over a rectangular 1000 m × 1000 m area for over 900 seconds of simulation time. In some of the existing simulation measurements [1] [13] [18], a narrow rectangular field of 1500m x 300m is commonly used to minimize the effect of network partitioning [13] and ensure that there is enough hops from source to destination when the transmission range of the nodes is 250 m [20]. However this kind of wide area topology does not provide enough space diversity for some applications. Nodes in the simulation move according to the Random Waypoint mobility model provided by GLOMOSIM. Mobility speed is ranged from 0-20 m/s and pause time is 0 s. In order to observe the behavior of the cross-layer framework, we considered a scenario with 3 multicast sources: one *RT* and two BE traffic sources sending to 15 multicast destinations in all experiments (assuming that all destinations were interested to receive from all sources). Each of the source generates a constant bit rate (CBR) traffic of 118kbps, a typical video conferencing data rate [1]. The radio transmission range is 250 m and the channel capacity is 2 Mbit/s. Each data point in this simulation represents the average result of ten runs with different initial seeds.

In MANETs, no benchmark metrics have been defined for evaluating performance of QoS provisioning [20]. *RT* multimedia applications such as video on demand and video conferencing have strict requirements for the delay, jitter and bandwidth while *BE* traffic may be more tolerant for these requirements. They require QoS support from the network in order to operate with acceptable quality. For this reasons, the efficiency of the proposed cross-layer framework is evaluated through the following performance metrics that have been studied in [2] and used by most studies into QoS of ad hoc wireless networks [1] [5] [21]:

- *Average packet delivery ratio (PDR):* The average of the ratio between the number of data packets received and the number of data packets that should have been received at each destination.

- *Control overhead (OH):* Number of transmitted control packet (request, reply, acknowledgment) per data packet delivered. Control packets are counted at each hop.
- *Average latency (AL):* the average end-to-end delivery delay is computed by subtracting packet generation time at the source node from the packet arrival time at each destination.
- *Jitter*: it is defined as a variation in the latency of received packets. It is determined by calculating the standard deviation of the latency [21].
- *Throughput:* the data rate in bits per second. It is computed as total number of bits received divided by the deference between the time for last packet received and the time for first packet.

4.1 The Performance of FQM vs. FQM-equal

As discussed previously, each type of application has different constraints and requirements. Without differentiating among different types of traffic; all types will affect each others. In this section we study the performance of FQM for *differentiates RT* and *BE* traffic and compare it with FQM-equal where there is no differentiating between *RT* and *BE* traffic; here all traffic flows have the same priority.

4.1.1 Packet Delivery Ratio (PDR) Comparison

The performance of PDR for all packets in relation to mobility is given in Figure 2. The PDR values for FQM-equal and FQM are relatively the same especially when the mobility increases. However, Figure 4 shows that FQM outperforms FQM-equal in term of AL. This is achieved via *RT* traffic getting high PDR at the expense of low PDR for *BE* traffic see Figure 5; although the average is the same as that achieved by FQM-equal.

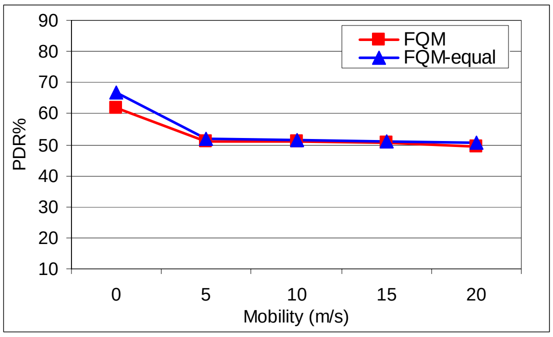

Figure 2: Performance of PDR vs. mobility.

4.1.2 Control Overhead (OH) Comparison

Figure 3 shows the Control OH vs. mobility. The control OH remains relatively constant in both approaches. From the simulation result, it seems that the control packets remain relatively constant vs. mobility because the forward nodes are updated periodically without any consider to the mobility, here an intelligent scheme can be used to adapt the interval time for updating the forward nodes based on the node mobility. This scheme will reduce the control OH especially with static and low node mobility. For our case, we choose a dynamic environment with high mobility 20 m/s to study the performance of the FQM framework. The results for control OH in Figure 3 show that control OH for FQM and FQM-equal is relatively the same and this reflects that FQM does not introduce any extra control OH to support RT traffic.

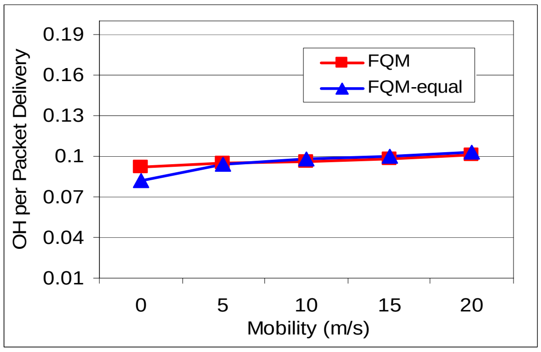

Figure 3: Performance of control OH vs. mobility.

4.1.3 Average Latency (AL) Comparison

All types of traffic in FQM-equal have the same priority so they affect each others. The intermediate nodes in FQM-equal become overloaded as a result of high traffic rate and increasing node mobility so the time spent waiting in the packet queue and contending for channel access increases. The results in Figure 4 show that the AL for FQM-equal is significantly higher than FQM; when the mobility increases the AL in FQM-equal increases dramatically. This reflects the ability of FQM to provide the same PDR as FQM-equal but with low AL to support *RT* traffic. This is because FQM uses several schemes to reduce the congestion and conserve bandwidth so packets (especially *RT* packets) do not take a long time to arrive at destinations.

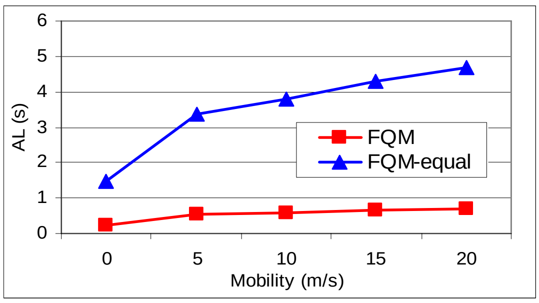

Figure 4: Performance of AL vs. mobility.

4.2 The Performance of FQM vs. QAMNet for different Mobility

In this section we compare the performance of FQM vs. QAMNet. Both approaches differentiate between *RT* and *BE* packets and use many mechanisms to priority *RT* traffic.

4.2.1 Packet Delivery Ratio (PDR) Comparison

The performance of PDR vs. mobility is given in Figure 5. For both approaches, the PDR of *RT* traffic is significantly higher than *BE* traffic, this is because *RT* traffic does not enter to the shaper and has high priority for sending to the channel. The PDR in FQM is significantly higher than QAMNet for both *RT* and *BE* traffic. In FQM, the request is accepted or rejected at each intermediate node and this saves the bandwidth. In QAMNet, the request is accepted or rejected only at the destination. The forward node will continue to forward requests even when there is not enough available bandwidth and this wastes bandwidth, affecting PDR. FQM saves bandwidth not only by filtering the requests at intermediate nodes when the available bandwidth cannot meet the required bandwidth, but also by dropping out of order packets and aged packets associated with high delay at the intermediate nodes. Avoiding relaying of packets that will be useless at destinations saves bandwidth, improves packet delay, preserve room for other packets in the queue and improves PDR [22]. In general, the results in Figure 5 show that FQM is superior to QAMNet in terms of PDR.

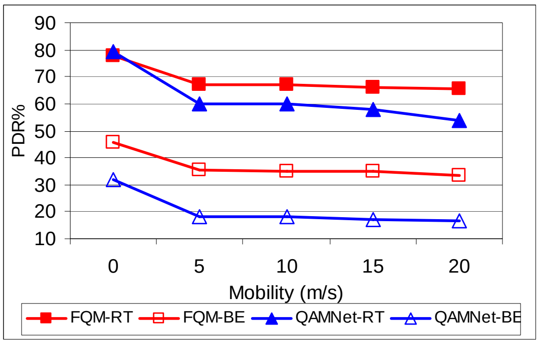

Figure 5: Performance of PDR vs. mobility.

4.2.2 Control Overhead (OH) Comparison

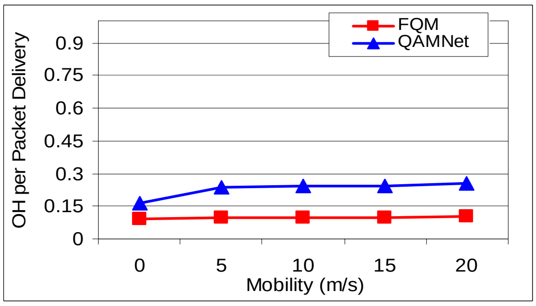

Figure 6: Performance of control OH vs. mobility.

Figure 6 shows the Control OH vs. mobility. The results show that control OH for FQM is significantly lower than QAMNet as mobility increases; this is because forward nodes estimate the available bandwidth and drop any requests that can not be accepted; the number of requests that will be forwarded decreases because the number of intermediate nodes that forward the requests decreases. The number of requests forwarded in FQM is lower than QAMNet by 58%. As a result of reduced congestion, the replies and acknowledgments are received correctly and this decreases the needs to resend replies due to congestion. The number of replies sent in FQM is less than QAMNet by 18%.

4.2.3 Average Latency (AL) Comparison

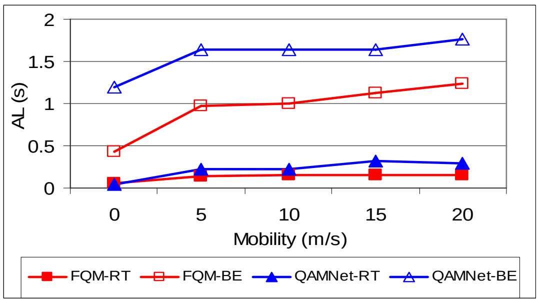

Figure 7: Performance of AL vs. mobility.

The number of nodes in the surrounding and the number of hops in the path between the source and destinations affect the end-to-end delay of packets [23]. For this reason, the QoS routing protocol needs to minimize the number of hops in the path; this objective is difficult to obtain with potentially unpredictable topology changes in MANETs [2]. The results in Figures 7 show that AL for FQM-RT is relatively lower than QAMNet-RT and AL for FQM-BE is significantly lower than QAMNet-BE. In QAMNet, the RT packets are entered to the shaper when the RTF_FLAG at the intermediate node is not set and this will introduces more delay for *RT* and *BE* packets. In addition, the control OH in QAMNet is quite high and this increase the congestion at the forward group. The AL in FQM is quite low because we used several techniques to reduce the congestion as mentioned in Section 4.2.1.

4.2.4 Jitter Comparison

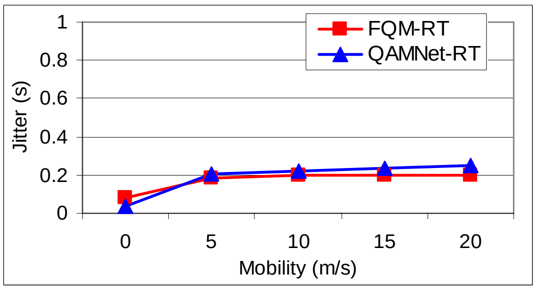

Figure 8: Performance of jitter vs. mobility.

Jitter occurs due to a temporally lack of wireless connections and scheduling issues on the link layer [24]. The number of hops in the path also affects the jitter because it affects the end-to-end delay [23]; it changes because the topology changes dynamically. Frequently changing routes could increase the jitter since the time for selecting forward nodes and the delay variation between the old and new routes increase the jitter. Figure 8 gives an overview on the performance of jitter vs. mobility. The results show that the jitter for *RT* in FQM and QAMNet are quite high even though jitter in FQM is less than QAMNet.

4.2.5 Throughput Comparison

The throughput vs. mobility is given in Figure 9. Throughput decreases because increasing mobility corresponds to decreasing PDR for both approaches. However throughput of FQM is significantly higher than QAMNet; this is because the PDR for FQM is higher than QAMNet; see Figure 5.

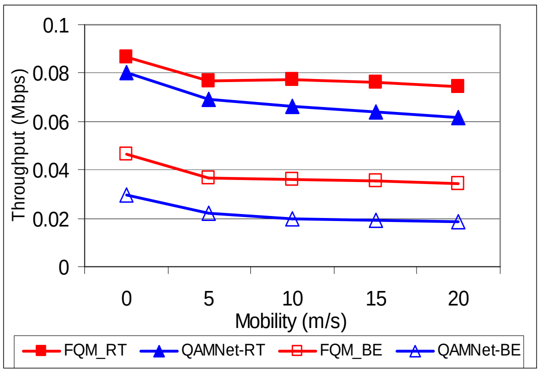

Figure 9: Performance of throughput vs. mobility.

4.3. The Performance of FQM vs. QAMNet for Varying Traffic Rates

The bandwidth of MANET is very limited. The throughput decreases as the number of hops in the path increases [25]. For the network capacity of 2 Mb/s, the achievable throughput is around 250–300 kb/s in the path with six hops. In general the capacity of long paths using the 802.11 MAC is around $\frac{1}{7}$ to $\frac{1}{4}$ of the raw channel bandwidth; this is because the multiple collisions that occur through neighbor nodes and also because the nodes in the path starve each others[14] [25] [26]. In this Section we study the performance of FQM and QAMNet approaches with different traffic rates. The speed of mobile nodes is fixed at 10 m/s for these experiments.

4.3.1 Packet Delivery Ratio (PDR) Comparison

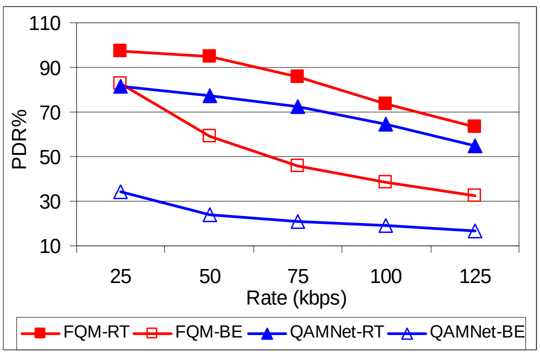

Figure 10: Performance of PDR vs. traffic rate

When the aggregate rate is higher than the maximum achievable throughput, packets are dropped at the interface queue and numbers of expired packets grows [25]. The performance of PDR vs. traffic rate is given in Figure 10. For both approaches, PDR starts at a high value and decreases when the traffic rate increases. The PDR in FQM is significantly higher than QAMNet for both RT and BE traffic because FQM uses several schemes to reduce congestion and conserve bandwidth. Figure 10 shows that FQM is superior to QAMNet in terms of PDR.

4.3.2 Control Overhead (OH) Comparison

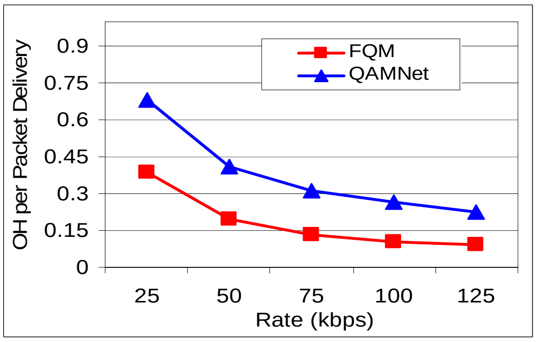

Figure 11: Performance of control OH vs. traffic rate.

The number of control packet transmitted remains approximately constant for different traffic rates. Consequently, ratio of control packets compared to data packets decreases for both approaches, because increasing the traffic rate corresponds to increasing the number of data packets while the number of control packets remain constant. Figure 11 shows the control OH vs. traffic rate. The control OH for FQM is slightly lower than QAMNet as traffic rate increases because FQM avoids relaying useless requests.

4.3.3 Average Latency (AL) Comparison

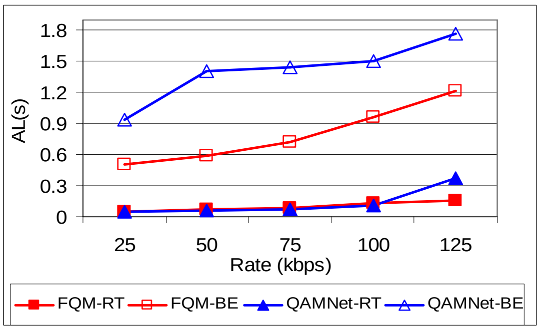

Figure 12: Performance of AL vs. traffic rate.

The results in Figure 12 show that when the traffic rate is low the AL values for RT in the two approaches are relatively the same; this is because the traffic is quite low so the congestion in QAMNet is low even though control OH is high. The AL for RT in QAMNet starts increasing more than FQM when traffic rate increases to more than 100 kbps. The AL for BE in FQM are significantly lower than QAMNet; this is because we used several techniques to reduce congestion. The high traffic leads to high delay due to MAC contention and long queues. The AL for BE traffic in the two approach is quite high because we use a shaper to regulate the BE traffic and the interface queue transmits RT with high priority.

4.3.4 Jitter Comparison

As described previously, many parameters affect packet delay. Figure 13 gives an overview of jitter vs. traffic rate. The results show that the jitter values for *RT* in both FQM and QAMNet are quite high.

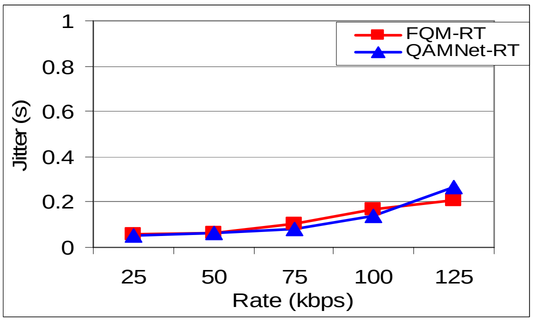

Figure 13: Performance of jitter vs. traffic rate.

4.3.5 Throughput Comparison

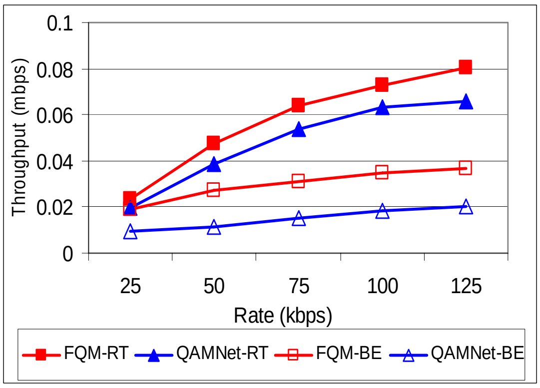

Figure 14: Performance of throughput vs. traffic rate.

Throughput vs. traffic rate is given in Figure 14. The throughput increases when the traffic rate increases, this is because increasing the traffic rate corresponds to increasing the number of data packets. The throughput of FQM is significantly higher than QAMNet for *RT* and *BE* traffic; this is because FQM reduces the congestion and conserve bandwidth so the number of lost data packets in FQM is low whereas in QAMNet, the number of lost data packets is high because the congestion is high.

5. Conclusion

In this paper, we presented a load balancing framework— FQM to support QoS multicast applications in MANETs. We proposed a QoS multicast routing protocol that uses a hybrid scheme to forward data packets. The hybrid scheme exploits the residual bandwidth efficiently by using redundant paths when the network bandwidth is sufficient or unipaths when the network bandwidth is strictly limited. The cross-layer design uses the passive listen method witch is an efficient way to estimate the available bandwidth with no control OH. Regulating BE traffic based on dynamic rate control improves the performance of *RT* traffic and gives *BE* traffic opportunity to use the residual bandwidth efficiently.

We studied the efficiency of FQM and compared it with FQM-equal and with QAMNet. We found that performing admission control at intermediate nodes is more effective than performing it at destinations. It prevents request packets from traveling unnecessarily throughout the network and this reduces control OH conserving bandwidth and balancing the load on the intermediate nodes. In addition, dropping the out of order packets and aged packets saves bandwidth, improves PDR and reduces AL and jitter. The classifier, shaper, rate control and priority queue mitigate the affect of the BE traffic on the RT traffic. The results show that FQM provides high PDR associated with low control OH, low AL and low jitter comparing with QAMNet. We can see that FQM out-performs QAMNet in most situations. This comes as a result of preventing overload, providing load balancing for Forward Nodes and mitigating the affect of BE traffic on RT traffic.

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