Estimated Bandwidth Distribution with Admission Control for Enhanced QoS Multicast Routing in MANETs

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---ABSTRACT---
Wireless networks become more widely used to support advanced services. Traditional approaches to guarantee quality of service (QoS) work well only with predictable channel and network access. The Multicast transmission is a more efficient mechanism when compared to uni-casting in supporting group communication applications and hence is an important aspect of future network developments. To enable high QoS for all admitted traffic, the Admission Control monitors the wireless channel and dynamically adapts admission control decisions to enable high network utilization while preventing congestion. Mobile Adhoc networks can provide multimedia users with mobility, if efficient QoS multicast strategies were developed. In load balancing QoS Multicast Routing QMR, constant available bandwidth for the link is assumed. A cross-layer framework to support QoS multicasting is extended for more effective than QMR. The extension reflects good packet delivery ratios associated with lower control overhead and lower packet delivery delay. If minimum real-time requirements are not met, these unusable packets waste scarce bandwidth and hinder other traffic, compounding the problem. Whereas the dynamically adapted mobility with control overhead monitors the high QoS for all admitted traffic, and the bandwidth for each node is enhanced to reflect the good packet delivery ratio associated with lower control overhead and lower packet delivery delay.

Key Words: **Admission control, Bandwidth estimation, Control overhead (OH), Delivery ratio, Load Balancing, QoS, QMR.**

Paper Submitted: 02 July 2009 Accepted: 13 September 2009

1 INTRODUCTION

In MANETs the bandwidth routing (BR) protocol [19] consists of an end-to-end path bandwidth calculation algorithm to inform the source node of the available bandwidth to any destination in the ad hoc network, a bandwidth reservation algorithm to reserve sufficient number of free slots for the QoS flow, and a standby routing algorithm to reestablish the QoS flow in case of path breaks. Here, only bandwidth is considered to be the QoS parameter. In TDMA-based networks, bandwidth is measured in terms of the number of free slots available at a node. The goal of the bandwidth routing algorithm is to find a shortest path satisfying the bandwidth requirement. The transmission time scale is organized into frames, each containing a fixed number of time slots. The entire network is synchronized on a frame and slot basis. Each frame is divided into two phases, namely the control phase and the data phase. The data phase is used for transmission/ reception of data packets. For each node a slot is assigned in the control phase for it to broadcast its routing information and slot requirements. At the end of the control phase, each node knows about the channel reservations made by its neighbors. This information helps nodes to schedule free slots, verify the failure of reserved slots, and drop expired real-time packets. The BR protocol assumes a half-duplex CDMA-over-TDMA [2,3] system in which only one packet can be transmitted in a given slot.

2. BANDWIDTH ROUTING

2.1 Bandwidth Calculation

Since the network is multi-hop in nature, the free slots recorded at each node may be different. The set of common free slots between two adjacent nodes denotes the link bandwidth between them. If the two nodes are adjacent, the path bandwidth between them equals their link bandwidth. For example, consider two adjacent nodes[15], node A and node B, having free slots {2, 5, 6, 8} and {1, 2, 4, 5}, respectively. The link bandwidth linkBW(A,B)=freeslot(A)\freeslot(B)={2,5 }. It means that only slots 2 and 5 can be used by nodes A and B for transmitting data packets to each other. The free slot(X) is defined as the set of slots which are not used by any adjacent node of node X (to receive or to send) from the point of view of node X. The BR protocol uses a heuristic-based hop-by- hop path bandwidth calculation algorithm to assign free slots at every hop along the path. The algorithm is explained with the help of the example, where a path from source node S to destination node D is illustrated.

The process of computing pathBW(S,D) is explained below.

- ✓ pathBW(S,A): Since node S and node A are adjacent, the pathBW(S,A)=linkBW(A,S), which is four slots. The four slots are {2, 5, 6, 7}.
- ✓ pathBW(S,B): Since pathBW(S,A)=link-BW(A,B)={2, 5, 6, 7}, if S uses slots 6 and 7 to send packets to A, then A can only use slots 2 and 5 for transmission of packets to B. This is because a node cannot be in transmission and reception modes simultaneously. Hence path- BW(S,B) is 2 slots, by assigning slots {6,7} on link(S,A) and slots {2, 5} on link(A,B).
- ✓ pathBW(S,C): Here slots 4 and 8 are exclusively available for linkBW(B,C), slot 2 is exclusively available for pathBW(S,B), and slot 5 is common for both of them. So assign one of slots 4, 8 to link(B,C), for example assign slot 4 to link(B,C), and slot 2 to path(S,B). For achieving maximum bandwidth assign slot 8 to link(B,C) and slot 5 to path(S,B). Hence pathBW(S,C) is 2 slots, by assigning slots {6, 7} on link(S,A), slots {2, 5} on link(A,B), and slots {4, 8} on link(B,C).
- ✓ pathBW(S,D): This case is similar to previous one. So slots 4 and 8 are assigned to path(S,C) and slots 3 and 5 are assigned to link(C,D) to get 2 slots for path BW(S,D).

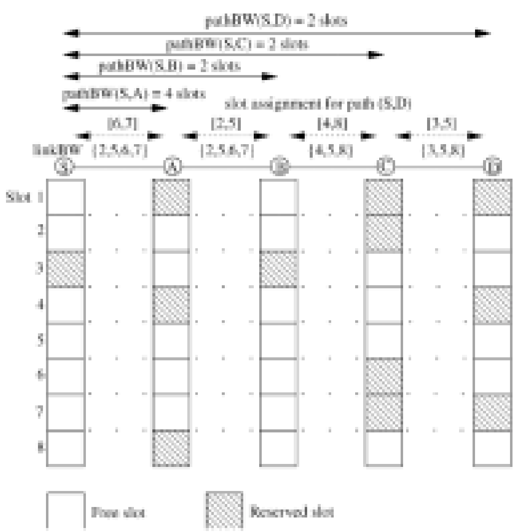

Fig. 1 An example of path bandwidth calculation in BR protocol.

2.2 Bandwidth Reservation

The destination node may receive one or more QRREQ packets, each giving a feasible QoS path for the connection request. The destination node selects the path with least cost among them and copies the fields {route list, slot array list} from the corresponding QRREQ[8,9] packet to the QoS route reply (QRREP) packet and sends the QRREP[9] packet to the source along the path recorded in route list. As the QRREP traverses back to the source, each node recorded in route list reserves the free slots that have been recorded in the slot array list field. Finally, when the source receives the QRREP, the end-to-end bandwidth reservation process[17] gets completed successfully and starts sending data packets in the data phase. The reservations made are soft state in nature in order to avoid resource lock-up.

2.3 Bandwidth Feasibility Test Phase

The objective of this phase is the selection of paths with required bandwidth. The source floods RREQ packets towards the destination. An intermediate node that receives this RREQ, checks for bandwidth availability in the link through which it received the RREQ packet. If sufficient bandwidth is available, then it forwards the RREQ packet, else it is dropped. The intermediate node adds its own reservation table along with the reservation tables of the nodes the packet has already traversed before forwarding it further. Routing loops are avoided by keeping track of the sequence number, source address, and traversed path information contained in the RREQ packet. Apart from this reservation table, an intermediate node also incorporates necessary information in an offset time field to enable the destination node to make use of the reservation table. When the RREQ packet is received at a node, the offset is increased by the estimated propagation delay of transmission. Hence by using this offset time, the relative difference between the local clock and the time information contained in the reservation table carried in the RREQ can be incorporated which can be used for synchronizing the reservation information. When the RREQ packet reaches destination, it runs the slot allocation algorithm on a selected path, after constructing a data structure called QoS Frame for every link in that path. The QoS Frame[6] is used to calculate, for every link, the free bandwidth slots in the super-frame and un-referable slots due to reservations carried out by the neighborhood nodes (also referred to as un-referable slots due to hidden terminals). The destination node waits for a specific time interval and gathers a set of RREQs and chooses a shortest path with necessary bandwidth.

2.4 Bandwidth Allocation Phase

In this phase, the destination node performs a bandwidth allocation strategy that assigns free slots to every intermediate link in the chosen path. The information about asynchronous slots assigned at every intermediate link is included in the route reply (RREP) packet and propagated through the selected path back to the source. Slot allocation strategies such as early fit reservation

Volume: 01, Issue: 02, Pages: 69-75 (2009)

(EFR)[5], minimum bandwidth-based reservation (MBR)[18], position-based hybrid reservation (PHR)[6], and k-hop count hybrid reservation (k-HHR)[7] are used for allocation of bandwidth and positioning of slots. The order of links in which it is chosen for allocation and the position of assigned bandwidth slots influence the end-to-end delay of the path and the call acceptance rate. MBR allocation scheme alone is discussed here.

Minimum bandwidth-based reservation (MBR): The following steps are executed by the destination node for the MBR scheme:

- ✓ Step 1: Order the links in the non-decreasing order of free bandwidth.
- ✓ Step 2: Allocate the first free slot in the link with lowest free bandwidth.
- ✓ Step 3: Reorder the links in the non-decreasing order of free bandwidth and assign the first free slot on the link with lowest bandwidth.
- ✓ Step 4: Continue Step 3 until bandwidth is allotted for all the links.

Fig. 2(b) shows the slot allocation carried out in MBR scheme over a simple string topology network. The worst case end-to-end delay provided by MBR can be (n1)·tsf where n is the number of hops in the path and tsf is the duration of super-frame. In the example in Fig. 2(b), the average delay experienced can be calculated as 33/3 slots.

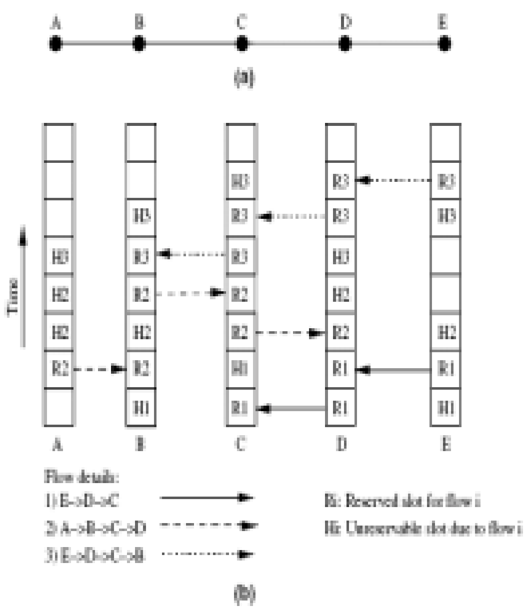

Fig. 2 Illustration of MBR scheme: (a) example network topology and (b) MBR scheme.

3. QOS FRAMEWORK FOR ADHOC NETWORKS

A framework for QoS is a complete system that attempts to provide required/promised services to each user or application. All components within this system cooperate together in providing the required services. The key component of any QoS framework[18] is the QoS model which defines the way user requirements are met. The key design issue here is whether to serve users on a per session basis or on a per class basis.

- ✓ Routing protocol: The routing protocol is used to find a path from the source to the destination and to forward the data packet to next intermediate relay node. The routing protocol needs to work efficiently with other components of the QoS framework in order to provide end-to-end QoS guarantees. These mechanisms should consume minimal resources in operation and react rapidly to changes in the network state and flow state.
- ✓ QoS resource reservation signaling: Once a QoS path is found, the resource reservation signaling protocol reserves the required resources along that path. For example, for applications that require certain minimum bandwidth guarantees, signaling protocol communicates with the MAC subsystem to find and reserve the required bandwidth. On completion/termination of a session, the previously reserved resources are released.
- ✓ Admission control: Even though a QoS feasible path may be available, the system needs to decide whether to actually serve the connection or not. If the call is to be served, the signaling protocol reserves the resources; otherwise the application is notified of the rejection. When a new call is accepted, it should not jeopardize the QoS guarantees given to the already admitted calls. A QoS framework is evaluated based on the number of QoS sessions it serves and it is represented by ACAR[14] metric. Admission control ensures that there is no perceivable degradation in the QoS being offered to the QoS sessions admitted already.
- ✓ Packet scheduling: When multiple QoS connections are active at the same time through a link, the decision on which QoS flow[20, 21] is to be served next is made by the scheduling scheme.

3.1 Source-Based Admission Control Of Real-Time Traffic

The process of admitting a new real-time session is as follows. The admission controller module at the source node sends a probing request packet towards the destination node to assess the end-to-end bandwidth availability. This is a best effort control packet that contains a bottleneck bandwidth field. Each intermediate node on the path between the source–destination pair that receives the probing request packet updates the bottleneck bandwidth field [16] in the packet if the bandwidth availability at the node is less than the current value of the field. On receiving the probing request packet, the destination node sends a probing response packet back to the source node with the bottleneck field copied from the received probing request packet. After receiving the response message, the source node admits the new real-time session only if sufficient end-to-end bandwidth is available. In this model, no bandwidth request is carried in the probing message, no admission control is done at intermediate nodes, and no resource allocation or reservation is done on behalf of the source node during the lifetime of an admitted session.

4. BANDWIDTH ESTIMATION

The available bandwidth estimated is based on the channel status of the radio and compute the idle periods of the shared wireless media. By using this method the activities of neighbors of node is considered; where any send or receive from other nodes will affect the channel status. In this method, for estimating the available bandwidth, each node can listen to the channel to determine the channel status and computes the idle duration for a period of time t; in our approach t = 1 s. In this case the IEEE 802.11 wireless radio has two states:

1- Busy state (transmitting, receiving and carrier sensing channel).
2- Idle state.

Each node will constantly monitor when the channel state changes; it starts counting when channel state changes from busy state (transmitting, receiving and carrier sensing channel) to idle state and stops counting when channel state changes from idle state to busy state. The Idle Time (T_i) is composed of several idle periods during an observation interval t; the node adds all the idle periods to compute the total idle time. The idle ratio (R) for each period of time t is calculated as:

$$R = T_i / t \quad (1)$$

The available bandwidth BW_{avail}:

$$BW_{avail} = R * BW \quad (2)$$

where BW is the raw channel bandwidth (2Mbps for standard IEEE 802.11 radio). After the node finishes computing the available bandwidth during a period of time t at the MAC layer, it sends the information of the available bandwidth to the Network layer and starts computing available bandwidth during the next period of time t. The work in [12] compared passive listening method with the active hello messages method and concluded that passive methods are straightforward and relatively accurate with no control overhead.

In our case, limiting overheads is a higher priority, so the passive listening method is used to estimate available bandwidth. The QMR protocol address the impact of mobility by updating forward nodes (FNs) periodically by freeing the allocated BW for old paths and allocating it for new paths. However, there might be an interval where FNs in the old path might not be aware that the amount of allocated bandwidth was changed since we use 5 second FN update intervals.

During this time, QoS requirements of other ongoing flows that use the same or nearby FNs are respected and protected [13]. This is better than using extra overhead to free the allocated bandwidths. This derived version of bandwidth estimation is E-QMR.

5. PERFORMANCE METRICS

The efficiency of the cross-layer framework is evaluated through the following performance metrics:

- ✓ *Average delivery ratio:* The average of the ratio between the numbers of data packets received and the number of data packets that should have been received at each destination.
- ✓ *Control overhead:* Number of transmitted control packet (request, reply, acknowledgment) per data packet delivered. Control packets are counted at each hop.
- ✓ *Average latency: the average* end-to-end delivery latency is computed by subtracting packet generation time at the source node from the packet arrival time at each destination.

The following metrics to *quantify the performance of Protocol*

- ✓ *Number of MPLS Trees* is the average number of MPLS (Multi-protocol Label Switching) trees maintained in the tree manager.
- ✓ *Number of Label Forwarding Entries* is the average number of label forwarding entries installed in all the routers (including the core routers and edge routers).

Request Rejection Ratio is defined as

$$RRratio(t) = N_R(t) / N_A(t) \quad (3)$$

where $N_A(t)$ denotes the number of group requests arriving in time period t after steady state is reached and $N_R(t)$ denotes the number of group requests which are rejected.

Tree Setup Ratio is defined as

$$TSratio(t) = N_A(t) - N_M(t) - N_R(t) / N_A(t) \quad (4)$$

where $N_A(t)$ and $N_R(t)$ are defined as above. $N_M(t)$ denotes the number of group requests which can be matched to some existing trees. TSratio(t) gives a measurement of tree setup overhead: the higher TSratio(t) is, the higher MPLS tree setup rate.

Real Bandwidth Waste Ratio is the percentage of bandwidth wasted due to leaky match between groups and trees. It quantifies the bandwidth overhead of the protocol.

Delay and Loss Ratio measure average end-to-end performance of the multicast trees. Delay is the amount of time to deliver a packet from a source to a receiver, which includes propagation, transmission and queuing delay. Loss ratio is defined as the percentage of data packets lost due to buffer overflow.

6 PACKET DELIVERY RATIO (PDR) VS. MOBILITY

Numerical results of the performance of PDR vs. mobility are given in *Tables 1 and 2*. As a result of using bandwidth estimation, admission control prevents FNs from being overloaded and provides load balancing which results in good PDR for E-QMR although it is less than the PDR for QMR. Without consequent the available bandwidth, FNs may become overloaded by forwarding extra control and data packets. This increases control overhead and data packet delay. In Table 2, when bandwidth requirement is 0.4 Mb/s, PDR for E-QMR and QMR are relatively similar although E-QMR is superior to QMR in control overhead and data packet delay.

6.1.1 The effect of different population sizes. Each value in *Table 1* is obtained by assuming that the bandwidth requirement is 0.2 Mb/s, number of mobile hosts is 50, 75, and 100; and mobility is 0-20 m/s. When the number of mobile host increases, the PDR increases because the chances increase for data packet to be forwarded instead of being dropped. PDR is still quite good with high mobility; because some forward nodes have enough residual bandwidth to forward data packets. FNs are updated periodically when new nodes participate in the network and establish new reservations even though older nodes are not longer available as FNs.

Table 1: Packet Delivery Ratio vs. Mobility for different population size

Mobiles per second	Packet Delivery Ratio in % for various Mobile Hosts					
	50 Mobile Hosts		75 Mobile Hosts		100 Mobile Hosts	
	QMR	EQMR	QMR	EQMR	QMR	EQMR
0	98.3	90.2	95.0	93.3	95.9	94.0
5	90.9	85.7	93.2	87.3	94.1	88.0
10	86.9	84.2	91.4	85.0	91.4	86.0
15	85.8	83.2	89.8	84.0	90.3	85.2
20	85.0	82.3	88.0	84.4	89.0	85.0

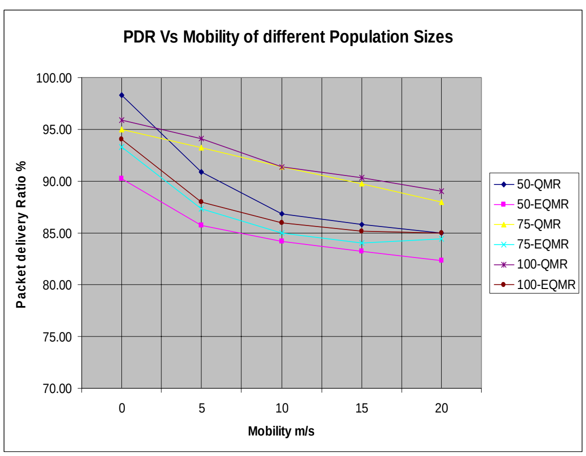

Fig. 3 Packet Delivery Ratio vs. Mobility for different population size

6.1.2. The effect of different bandwidth requirements. Each value in Table 2 is obtained by assuming that the bandwidth requirement is 0.1, 0.2, and 0.4 Mb/s, mobility is 0-20 m/s and number of mobile hosts is 75. The results show that PDR decreases when bandwidth requirements increases, this is because FNs do not have available bandwidth to forward data packet with high bandwidth requirements. The PDR decreases when mobility increases, because FNs lost their bandwidths as a result of mobility and interference between neighbors.

Table 2: Packet Delivery Ratio vs. mobility for different bandwidth requirement

Mobiles per second	PDR vs. Mobility for different Bandwidth Requirement					
	BW Req. : 0.1		BW Req. : 0.2		BW Req. : 0.4	
	QMR	EQMR	QMR	EQMR	QMR	EQMR
0	99.70	98.70	95.00	93.30	73.80	73.00
5	99.50	97.12	94.36	91.00	71.29	71.00
10	99.46	97.67	92.00	88.56	69.05	69.19
15	99.00	97.23	90.81	86.23	67.54	67.10
20	99.00	95.00	88.00	84.50	64.00	65.00

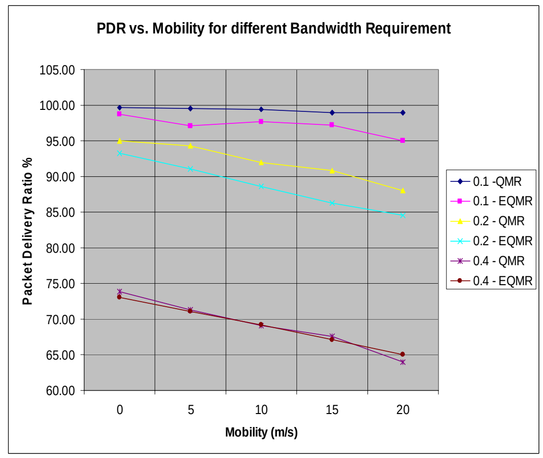

Fig. 4 Packet Delivery Ratio vs. mobility for different bandwidth requirement

6.2. Control Overhead (OH) vs. Mobility

Control OH vs. mobility observed using numerical analysis results are given in Table 3 and 4. To study the performance of control OH, two kinds of effects are analyzed. MANETs are very sensitive to the control OH as its bandwidth is very limited.

The results for control OH in Table 3 and 4 show that control OH for E-QMR is significantly lower than QMR, this is because FNs estimate the available bandwidth and drop any *Request*s and *Replies* for other flows; this avoids wasting bandwidth by forwarding *Request*s and *Replies* for flows that can not be admitted.

6.2.1. The effect of different population sizes. Each value in Table 3 is obtained by assuming that the bandwidth requirement is 0.2 Mb/s, number of mobile hosts is 50, 75, and 100; and mobility is 0-20 m/s. Generally, the control OH increases slowly when mobility increases, because there is no extra control OH to update FNs or extra signaling to estimate the available bandwidth. In addition, E-QMR has lower Control OH compare with QMR.

Table 3: Control OH vs. mobility for different population sizes

Mobiles per second	Control Overhead per Packet Delivery					
	50 Mobile Hosts		75 Mobile Hosts		100 Mobile Hosts	
	QMR	EQMR	QMR	EQMR	QMR	EQMR
0	0.520	0.380	0.453	0.412	0.451	0.420
5	0.512	0.402	0.469	0.424	0.463	0.427
10	0.528	0.434	0.481	0.433	0.476	0.431
15	0.532	0.458	0.505	0.440	0.489	0.436
20	0.536	0.470	0.462	0.452	0.495	0.440

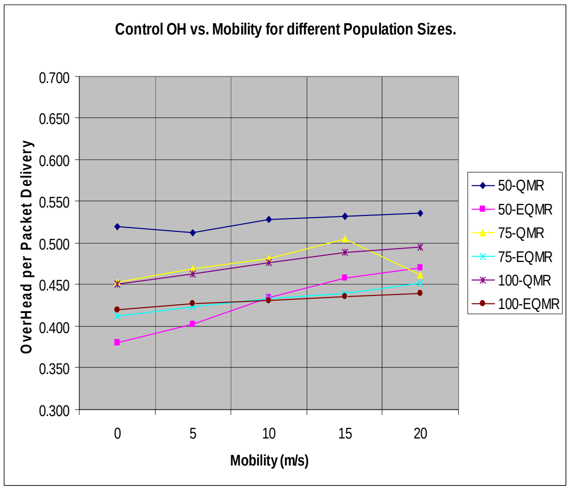

Fig. 5 Control OH vs. mobility for different population sizes

6.2.2. The effect of different bandwidth requirements. Each value in Table 4 is obtained by assuming that the bandwidth requirements is 0.1, 0.2, and 0.4 Mb/s, mobility is 0-20 m/s and number of mobile hosts is 75. It is observed that Control OH decreases as bandwidth requirements increase because admission control prevents FNs from relaying extra Requests and Replies packets. Similarly E-QMR performs better than QMR in Control OH is numerically proved.

Table 4: Control OH vs. Mobility for different bandwidth requirements

Mobiles per second	Control OH vs. mobility for different bandwidth requirements					
	BW Req. 0.1		BW Req. 0.2		BW Req. 0.4	
	QMR	EQMR	QMR	EQMR	QMR	EQMR
0	0.550	0.450	0.453	0.410	0.356	0.340
5	0.588	0.460	0.470	0.420	0.370	0.364
10	0.591	0.469	0.492	0.440	0.380	0.377
15	0.593	0.462	0.493	0.450	0.400	0.385
20	0.595	0.480	0.462	0.450	0.417	0.390

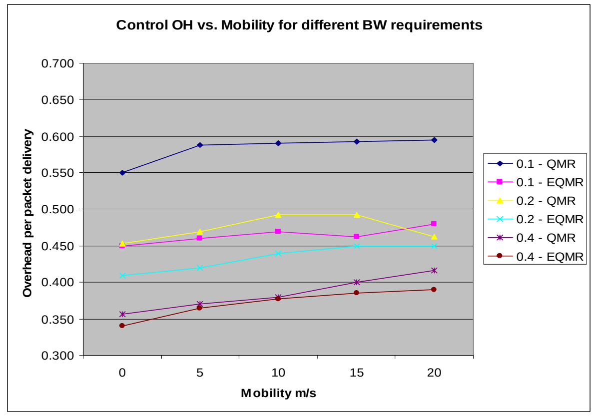

Fig. 6 Control OH vs. mobility for different bandwidth requirements

7. CONCLUSIONS AND FUTURE WORK

The effectiveness of the cross-layer approach is evaluated by conducting numerical assessments. The main concern of these assessments is to evaluate the E-QMR's efficiency for supporting QoS multicast compare with the QMR approach. In the future the above numerical results can be experimented using GLOMOSIM [14] by assuming a MANET with 50-100 nodes moving over a rectangular 1000 m × 1000 m area for over 600 seconds of duration. The multicast traffic sources in these evaluations are constant bit rate (CBR) traffic. Each traffic source originates 512-byte data packets. The range of mobility speed is 0-20 m/s and pause time is equal to 30 s. In order to observe the behavior of the sub cross-layer framework, and considering a scenario with 3 multicast sources and 15 multicast destinations the results (assuming that all destinations were interested to receive from all sources and sources use same bandwidth requirements) may be specially described. The transmission range of each node has to be observed with raw data rate. For all these, the minimum bandwidth requirements are considered as 0.1, 0.2, and 0.4 Mb/s. The IEEE 802.11 MAC may also enhance to estimate the available bandwidth using equation (2).

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