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QoS-aware Multicast Ad hoc On-Demand Distance Vector Routing

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***Abstract*—Ad hoc networking will become a major technology for wireless connectivity beside the multimedia necessity within the next few years. There are too many applications where one-to-many dissemination is necessary. Most of these applications are characterized by the close collaboration teams with requirements for audio, video conferencing and data sharing which QoS parameters such as bandwidth and delay are very critical for them.**

In this paper, an efficient algorithm named is proposed to improve the route discovery mechanism in MAODV for QoS multicast routes. QoS-MAODV especially can establish a multicast tree with the minimum required bandwidth support and decrease the end-to-end delay between each destination and the source node. It can establish QoS routes with the reserved bandwidth on per chosen flow. To perform accurate resource reservation, we have developed a method for estimating the consumed bandwidth in multicast trees by extending the methods proposed for unicast routing. The simulation results show that QoS-MAODV protocol produces higher throughput and lower delay in comparison with MAODV protocol.

***Index Terms*—Mobile Ad hoc Networks, QoS, Multicast Routing, Bandwidth Reservation.**

I. Introduction

Recent progresses in the network technologies have led to rapid development of new wireless networking techniques and possibilities. An example of such a new wireless network is Mobile Ad hoc Network. On the other hand, the demand for new applications with new requirements is developed. One of the most demanding applications is multimedia application. Multimedia application characterized with the requirements for voice and video conferencing, and text and images sharing. These new requirements have led to necessity of supporting real-time traffic. Real-time applications are highly sensitive to latency and other quality of service parameters such as bandwidth. Ad hoc networks have numerous practical applications such as military and emergency operations. These practical applications need the support of one to many, and many to many connections. Therefore, in such practical applications, multicast communication is a must. QoS routing, especially QoS multicast routing, is very crucial for these applications. QoS routing protocols search for routes with sufficient resources in order to satisfy the QoS requirement of a flow. The information of resource availability in each node is required for doing admission control in routing mechanism. However, each node needs the information of channel resources as consumed or available. Considering this information, each node decides about the collaboration in the route. For the discovered routes which provide QoS requirements, the admission control policy guarantees the requested minimum bandwidth.

Estimating available bandwidth in IEEE 802.11 MAC in mobile ad hoc networks is still a challenging problem. Therefore, we tried to solve it and estimate available bandwidth in network layer independent of MAC layer. There are some proposed mechanisms for establishment of consumed channel resources like bandwidth for nodes in unicast routing [1]. But, there are not such mechanisms for multicast routing. The bandwidth is shared among neighboring nodes. A node in multicast tree can have more than one downstream node as its neighbors. Each downstream node can have downstream nodes again. Therefore, the estimation of available bandwidth in the networks with multicast sessions is more challengeable.

In this paper, we estimate the available bandwidth based on the information that each node receives from its neighbors in control messages in the route discovery phase. Our proposed protocol, QoS-MAODV extends existing Multicast Ad hoc On-demand Distance Vector Routing (MAODV) protocol by using admission control and bandwidth reservation in each node. MAODV protocol is specifically designed for ad hoc networks. MAODV is based on bidirectional shared trees that are created and terminated as the multicast receivers join and leave the multicast groups [2], [3].

The rest of the paper is organized as follows. Section 2 provides an overview of related works in the area of QoS multicasting in mobile ad hoc networks. In section 3, we introduce the proposed QoS-MAODV protocol. In section 4, we demonstrate the calculation of the consumed and available bandwidth in the nodes of a multicast tree. The simulation results are studied in section 5, and section 6 concludes the paper.

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II. The Related Works

Several protocols have been developed for supporting ad hoc multicast routing, i.e. MAODV [2]–[3], ODMRP [4], and CAMP [5]. However, these protocols did not address the QoS aspects of ad hoc wireless communication. Only a few protocols support QoS in multicast routing in mobile ad hoc networks. Examples are QAMNet [6], QMR [7], E-QMR [8] and Lantern-trees [9].

The QAMNet [6] approach extends the mesh-based ODMRP multicast routing protocol by introducing traffic prioritization, distributed resource probing and admission control mechanisms to provide QoS. For available bandwidth estimation, it compared the threshold rate of real-time traffic and current rate of real-time traffic. This is the same as method of SWAN [10]. Similarly, it has many difficulties to estimate the threshold rate accurately because of its dependence to the traffic pattern.

The QMR protocol integrates bandwidth reservation function into a multicast routing protocol. It assumes that available bandwidth is constant and equal to the raw channel bandwidth.

The E-QMR also uses the estimation of available bandwidth for admission control. This admission control at the network layer makes a decision to accept or reject the new request depends on the information that comes from MAC layer.

Most of these protocols have some problems, because they estimate the available bandwidth based on the channel status. Each node can listen to the channel to determine the channel status and computes the idle duration only for a period of time.

A lantern-tree topology is used to provide QoS multicast routing in [9]. This protocol shares time slots at the Mac layer and uses a CDMA over TDMA channel model. In this model, available bandwidth is measured in terms of the amount of free slots. At startup, it shares time slots between all neighbor nodes and finds a suitable scheduling of the free slots. Its main disadvantage is the need for a centralized MAC scheme in ad hoc mobile networks with dynamic wireless environments.

III. The Proposed Protocol

QoS-MAODV is a tree-based multicast routing protocol based on MAODV protocol. Similar to MAODV [2,3], and AODV [11], it creates the routes on-demand and makes the shared trees. Route discovery is based on a route request and route reply cycle. To provide quality of service, we added extensions to these messages during the route discovery process.

In QoS-MAODV protocol, we use admission control to prevent intermediate nodes from being overload. If there is no available bandwidth, the intermediate node will reject Rreqs of new sessions. When an intermediate node receives a QoS-Rreq, and has enough available bandwidth, it accepts the Rreq.

A. Data Forwarding

For each multicast group, the tree contains the members of two distinct classes of nodes, the nodes joined the multicast tree (source or destination nodes), and the nodes not joined the multicast group but are forwarding the multicast group packets towards other nodes in the tree. Both classes must reserve the required bandwidth for the multicast packets.

B. Message Types

QoS-MAODV protocol uses six different message types for creation of QoS multicast tree. These messages are:

- Route request (Rreq)
- Route reply (Rrep)
- Multicast activation (Mact)
- Group hello (Grph)
- Hello
- QoS-lost

All of these messages are also used in MAODV protocol except QoS-lost. QoS-lost message informs the other nodes that the reserved bandwidth is no longer available. The format of these messages remains as specified in [2] except that we add some flags and extensions for bandwidth and state of reservation especially for Hello message. In our protocol, the Grph and Hello messages are also responsible for update the bandwidth reservations in the nodes. Therefore, the nodes which do not receive these packets in certain time will release the reserved bandwidth or change the state of reservation.

C. Control Tables

MAODV keeps a routing table for multicast routes and a multicast group leader table to optimize the routing. Similarly, QoS-MAODV has these two tables. In addition a node may also keep these following tables:

- Bandwidth reservation table

It is used to keep bandwidth reservation information for different groups. The entries in this table have the following attributes: multicast group address, Amount of reserved bandwidth, state of the reservation, time stamp, hop count from the source node, and IP address of the source node.

- Neighbors table

This table keeps information of neighbors such as neighbor address, amount of reserved bandwidth in neighbor node, state of the reservation, amount of consumed bandwidth in neighbor, state of neighbor (sender, receiver or forwarding node), and time stamp.

- Multicast Consumed bandwidth

It keeps required information for calculation of consumed bandwidth in each node. Normally reserved bandwidth for uplink and downlink nodes in multicast tree and the state of reservation are kept in this table.

D. QoS-MAODV Mechanism

When a multicast source requires a route to a multicast group, it broadcast a Rreq message with the bandwidth field set

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to the required bandwidth, join flag set to true, and destination address set to the multicast group address. A member of multicast tree with a current route to the destination and enough amount of available bandwidth responds to the request with a Rrep message. A node receiving Rreq message with a quality of service extension will rebroadcast the message only if it can able to meet the service requirement. Each node accepting the Rreq message will reserve the required bandwidth as allocated state. Allocated state is not a real reservation; it is a notification of acceptance for the node itself and its neighbors. It updates its tables and records the sequence number and next hop information for the source node. This information is used to send the Rrep message back to the source.

When the source node receives the Rrep message, it reserves the required bandwidth as temporary-reserved and calculates the end-to-end delay of each path. If the source node receives multiple Rreps from different paths for its Rreq message, it chooses the best path with the minimum end-to-end delay and the minimum hop-count to group leader. It then sends a multicast activation (Mact) message which is used to activate the chosen path from the source to the destination node sending the Rrep. The Mact message in its path to the multicast group changes the state of bandwidth reservation from temporary-reserved to the reserved. If the intermediate nodes do not receive a Mact message within a certain time period, they will free the temporary-reserved bandwidth. If a source node does not receive a Rrep in certain time period, it will broadcast another Rreq. After a certain number of retries, the source node assumes that there are no other members of the tree that can be reached with the required bandwidth, and declares itself as the group leader. The group leader is responsible for periodically broadcasting group hello (Grph) messages to maintain group connectivity. In the Grph message, group leader informs the other nodes about existence of the multicast group, and its reserved bandwidth. The nodes in reserved state will release the reserved bandwidth if they do not receive the Grph messages within a certain time period. Each node also periodically broadcasts Hello messages for one hop neighbors to maintain local connectivity and to inform them about the reserved bandwidth in the channel and the state of reservation.

After establishment of such a route, if any node along the path detects that the requested quality of service parameters can maintain no longer, that node must originate a QoS-lost message back to the node which had originally requested the now unavailable parameters [12].

Algorithms that provide QoS support in Ad hoc mobile networks should include accurate measurement of the bandwidth availability in the shared wireless channel and accurate measurement of effective end-to-end delay in an unsynchronized environment [1]. In particular, the QoS-MAODV protocol needs to know the exact value of consumed bandwidth in the channel to make decision in the route discovery phase. Therefore, we need to calculate the consumed bandwidth for each node. The estimation of the available bandwidth and the consumed bandwidth of channel is studied in unicast routings [1].

IV. Admission Control

To provide QoS requirements on a path, the admission control policy should guarantee the requested minimum bandwidth B_{min} for each flow. Bandwidth reservation by admission control is made at every node in the route setup phase based on the calculations as described in the next section.

A. Bandwidth Control

To determine if there is enough bandwidth for a new flow J, all we need to know is the available link capacity and the bandwidth will be consumed by the flow. Because of the characteristics of the shared medium, a node can successfully use the channel only when all its neighbors do not transmit any packets at the same time [1]. As illustrated in [1], the available bandwidth estimation is lower than the real accessible bandwidth in the channel by the amount of the neighborhood traffic.

In (1) $B_{self}(I)$ can be defined by the total reserved bandwidth of all existing flows at node I for all nodes J in the neighborhood of node I [1].

Available bandwidth at node I can be given by [1]:

$$B_{self}(I) = \sum_{k} B_I(k) \tag{1}$$

$$B_{available}(I) = B - \sum_{j \in N(I)} B_{self}(j) \tag{2}$$

Where B is the raw data rate of the node I, and $B_{self}(j)$ is the total traffic between node j and its neighbors, i.e., the bandwidth consumed by the traffic transmitted or received by node j. Given the requested bandwidth B_{min}, the bandwidth to be reserved for the flow j at node I is:

$$B_I(j) = \begin{cases} B_{min} & \text{if } I \text{ is the source or the destination} \\ 2B_{min} & \text{otherwise} \end{cases} \tag{3}$$

Since the intermediate nodes need to receive and forward flow j [1].

As illustrate in [1], the consumed bandwidth for flow j on node I's channel can be given by:

$$B_{consumed}(I, j) = B_{uplink(I)}(j) + B_{downlink(I)}(j) \tag{4}$$

Where $B_{upli0nk(I)}(j)$ is the reserved bandwidth for flow j on the upstream neighbor of node I, and $B_{downlink(I)}(j)$ is the bandwidth that the downstream neighbor of node I reserved for flow j. Note that $B_{uplink(I)}(j)$ and $B_{downlink(I)}(j)$ can be either equal to B_{min} or $2B_{min}$ as shown in (3) for unicast flows. In unicast protocols each node only has one upstream and one downstream node, therefore equation (4) can be used for estimating the consumed bandwidth. But in multicast protocols, each node may have more than one downstream node as a forwarding group. Therefore, equation (4) can not be used as an estimation of the consumed bandwidth.

We propose a new technique for estimating the consumed bandwidth in multicast protocols. Note that $B_{uplink(I)}(j)$ can be either equal to B_{min} or $2B_{min}$ as shown in (3). For estimation of $B_{downlink(I)}(j)$, we must note that there are two kinds of downlink nodes: forwarding nodes, and receiver nodes. Suppose d_r be the number of receiver downlink nodes, and d_f be the number of forwarding downlink nods. In multicast trees, d_r and d_f can be 0 or greater than one.

We can calculate the bandwidth that the downstream neighbors of node *I* reserved for flow *j* by:

$$B_{down}(I,j)=\begin{cases}\left\lceil \dfrac{d_r}{d_r+1}\right\rceil * B_{\min} & d_r>0, d_f=0\\ (1+d_f)*B_{\min} & d_r\geq 0, d_f>0\end{cases} \qquad (5)$$

Assume that node *I* has some downstream nodes and now a new node is added to its neighbors as a new downlink node. If this node is a receiver downlink node, the $B_{downlink(I)}(j)$ will not change. However, if it is a forwarding downlink node, the $B_{downlink(I)}(j)$ will be added with B_{min} or $2B_{min}$ based on the number of d_f nodes that are neighbors of node *I*.

By comparing the values of $B_{available}(I)$ and $B_{consumed}(I, j)$, each node can now decide whether to accept the flow or not [1].

V. Simulation Results

A. Simulation Environment

The simulation was implemented by using the Qualnet [13]. QualNet software is used to develop new communication technologies through network modeling and simulation [13]. The proposed simulation scenarios model a network of 50 mobile hosts placed randomly within a 1000×1000m^2 area. Radio propagation range for each node is selected as 250 meters and the channel capacity is set to 2Mbit/sec. Each simulation scenario executed for 300 seconds. The IEEE 802.11 Distributed Coordination Function (DCF) [14] was used as the medium access control protocol. We used Constant Bit Rate as the source of traffic. The size of data payload was 1024 bytes. We used Random-Way point as the mobility model. In this model, each node randomly selects the moving direction, and when it reaches to the simulation terrain boundary, it bounces back and continues to move.

B. Methodology

To evaluate the performance of *QoS-MAODV*, we simulated and compared the following schemes:

- MAODV (Multicast Ad hoc On-demand Distance Vector Routing)

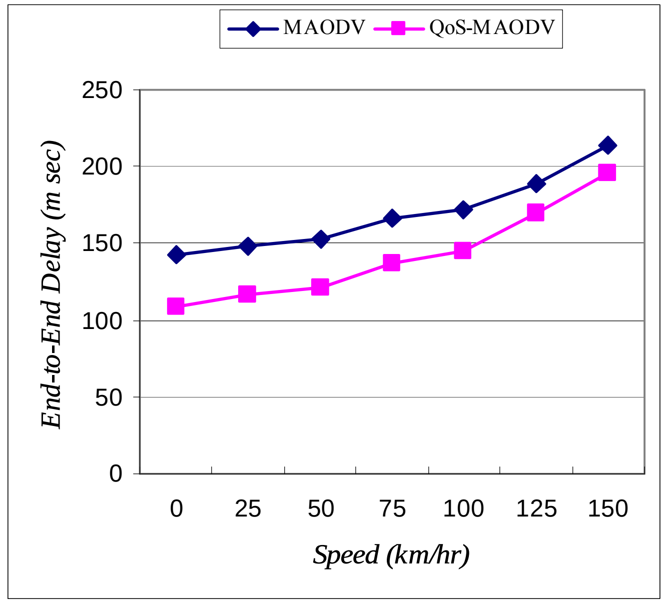

Figure 1: End to End Delay Vs Mobility

- QoS- MAODV

We evaluated both schemes as a function of speed and group size (number of receivers). For evaluation of the effect of speed, group size was fixed at 3 and the speed was varied between 0 and 150 Km/hr and the pause-time was set to 3 seconds. Each multicast group had 5 members that were selected randomly from 50 nodes of the network. Sessions were established with the interval time of 5 seconds and remained until the end of simulation time.

The performance of the proposed protocol is evaluated through seven scenarios. Suppose the source node of the group *i* will send data traffic with the rate of C*i*Kbits/s. Each scenario is shown with an order list (C1, C2, C3), represented with a data rate of each of three multicast groups. We have selected the following seven scenarios: {128, 128, 128}, {256, 256, 256}, {512, 512, 512}, {128,256,128}, {128, 512, 128}, {512, 256, 256}, and {512, 256, 512}.

For evaluation of the effect of the group size, the speed of each node was set to 0. We had one sender and the group size varied from 3 to 30, incremented with step of 3. We collected the following performance metrics:

Packet Delivery Ratio: The number of data received by the destinations over the number of data sent by the sources.

QoS Destinations Packet Delivery Ratio: The number of data received by the destinations over the number of data sent by the sources only for the destinations that a QoS route was discovered.

End-to-End Delay: the latency incurred by the packets between their generation time and their arrival time at the destination.

C. Simulation Results

We can observe in Fig. 1 that as the speed of the nodes increases, the End-to-End delay increases in both of MAODV

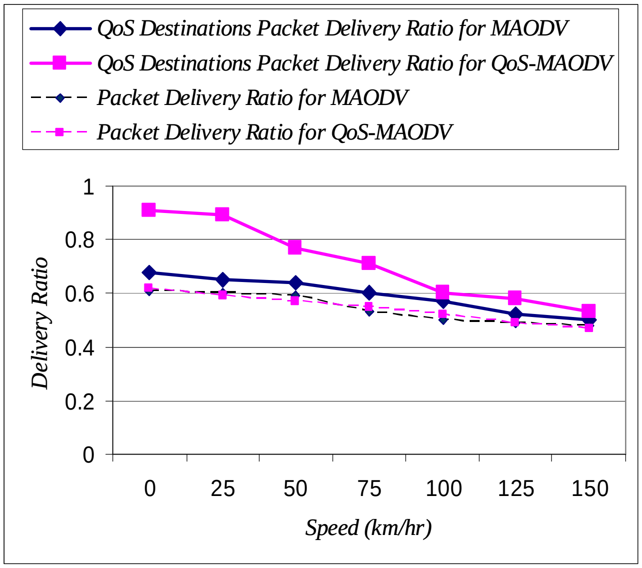

Figure 2: Packet Delivery Ratio Vs Mobility

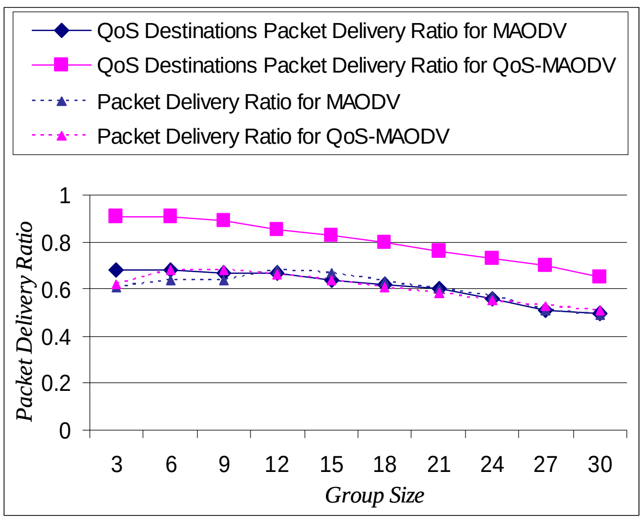

Figure 3: Packet Delivery Ratio Vs Group Size

and QoS-MAODV (because of frequent link breaks). However, QoS-MAODV performs better (It does not waste the resources of the network). QoS-MAODV decreases queuing delay at each relaying node. Since each node in wireless network has only one output queue, any reduction in average queuing delay decreases the average End to End delay. The reservation of the bandwidth and not starting unsuccessful flows lead to the reduction in End to End delay.

The packet delivery ratio as shown in Fig. 2 and Fig. 3 is not very different from MAODV. Since MAODV and also QoS-MAODV protocols will start session if they find only one of the destinations available. We introduced the QoS destinations packet delivery ratio as a new performance metric. Simulation results show that QoS-MAODV will improve QoS destinations packet delivery ratio. QoS-MAODV reserves the required bandwidth and improves packet delivery ratio for the admitted destinations.

VI. Conclusion

In this paper we have extended MAODV protocol to support QoS multicasting by estimating the available bandwidth. We have proposed a method to estimate the consumed bandwidth of the channel for a multicast node with more than one downlink neighbors. The performance of QoS-MAODV is studied by extensive simulations using QualNet simulator. We defined the following performance metrics for QoS support in multicast routing: the packet delivery ratio, QoS destinations packet delivery ratio, and the average End-to-End delay. The simulation results show that QoS-MAODV can successfully provide better QoS support in multicast routing in mobile ad hoc networks. QoS-MAODV will calculate the required bandwidth for each session and reserve it for the related multicast tree. QoS-MAODV will not waste the resources of the network for the unreachable paths and destinations. QoS-MAODV filters unreachable paths in the route discovery phase. The results justify that QoS-MAODV provide minimum bandwidth guarantee for the flows. In this way, QoS-MAODV clearly decreases the queuing delay in the nodes of the network. Decreasing the queuing delay will lead to the reduction of End-to-End delay. The simulation results show the reduction of End to End delay for each session. We calculated End to End delay for all sessions and compared it with MAODV. The simulation results show better performance for QoS-MAODV in most senarios.

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