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Hidden Route Aware QoS Routing Protocol for Mobile Multimedia Ad Hoc Networks

Yu-Liang Kuo*, Eric Hsiao-Kuang Wu†, and Gen-Huey Chen*
* Dept. of Computer Science and Information Engineering, National Taiwan University, Taipei, Taiwan, R.O.C.
†Dept. of Computer Science and Information Engineering, National Central University, Chung-Li, Taiwan, R.O.C.

Abstract – This paper proposes a QoS routing protocol for multimedia services in mobile ad hoc networks (MANETs). We adopt a new distributed MAC protocol, called enhanced distributed channel access (EDCA), that has being developed by IEEE 802.11 working group to support service differentiation. In order to satisfy the QoS requirements such as required bandwidth and end-to-end delay for different source-destination transmission pairs, it requires a QoS routing protocol to discover routes with QoS guarantees. The proposed QoS routing protocol discovers routes for source-destination transmission pairs with bandwidth and end-to-end delay guarantees. The procedures of neighborhood maintenance, QoS violation detection, and route maintenance are also presented in this paper.

Furthermore, we introduce a new problem called hidden route problem, which is arising because of existing routes that are hidden for the current route discovery procedure. The problem is also solved in the proposed QoS routing protocol. We use the ns-2 simulation to evaluate the performance of the proposed QoS routing protocol and compare it with other ad hoc QoS routing protocols. Simulation results show that the performance criteria, such as packet delivery ratio and average end-to-end delay, outperform other existing QoS routing protocols with the sacrifice of routing overhead under light load conditions.

Key-Words: Ad hoc network, multimedia, QoS, routing protocol.

1. Introduction

A MANET is a collection of mobile nodes, in which each node can communicate with one another without the aid of any centralized access point or existing infrastructure. Typically, in order to transport data from one mobile node to another one, a route for a source-destination transmission pair that consists of multi-hop transmission should be established before transmission. Recently, due to the provisioning of high-speed wireless environments, multimedia services (e.g., VoIP and video-conference) with different QoS requirements such as required bandwidth and delay-sensitivity will be available in MANETs. Hence, multimedia services will be categorized into multiple traffic classes and different priorities will be applied to access the wireless medium in each hop transmission. However, in the current access mechanisms, all mobile nodes have the same priority to access the wireless medium. In order to support multiple priorities among different traffic classes, it is desired to provide service differentiation mechanisms in the MAC layer.

IEEE 802.11 working group has been developing a new distributed MAC protocol, called enhanced distributed channel access (EDCA), to support service differentiation in the MAC layer [3]. EDCA is an extension of existing distributed coordination function (DCF) [1] which is based on carrier sense multiple access/collision avoidance (CSMA/CA). EDCA provides service differentiation by assigning different values of access parameters among different traffic classes. Multiple priorities can be supported for different traffic classes to access the wireless medium. More detailed reviews about DCF and EDCA will be presented in Section 2.

However, supporting service differentiation in the MAC layer does not guarantee the QoS requirements of multimedia services in each hop along a route. Hence, it is desired to design a routing protocol that is tailored for multimedia services, in which the QoS requirements such as bandwidth of each hop and delay along the route can be satisfied.

QoS routing in MANETs has been receiving increasingly intensive attention in recent literature [5], [8], [10-12]. In [8] and [11], the CDMA-over-TDMA MAC layer protocol is used to eliminate the interference among different transmissions of multimedia applications. The proposed solutions described in [8] and [11] mainly focus on allocating the time slots to different transmissions. However, it is difficult to realize the CDMA-over-TDMA MAC protocol in a distributed environment.

The MAC layer protocols based on CSMA/CA, e.g., DCF and EDCA, are common used in wireless networks. It provides the features of simplicity, convenience, and flexibility to pave the underlying MAC protocol in MANETs. In [10], the MAC layer protocol is based on CSMA/CA and the routing protocol adopts a table-driven method. The yellow and green tickets are issue to maximize the probability of finding a feasible path and maximize the probability of finding a low-cost path, respectively. However, existing investigations [4], [7] show that a table-driven protocol is more liable to suffer performance degradation than an on-demand protocol because of the stale route information.

The MAC layer protocol used in [5] and [12] are also based on CSMA/CA but the routing protocols are on-demand. However, the protocols will suffer from a problem, named as *hidden route problem*, which will be presented in the following paragraph. All the underlying MAC layer protocols described in [10], [5] and [12] are based on CSMA/CA and will suffer

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from the hidden route problem in the network layer.

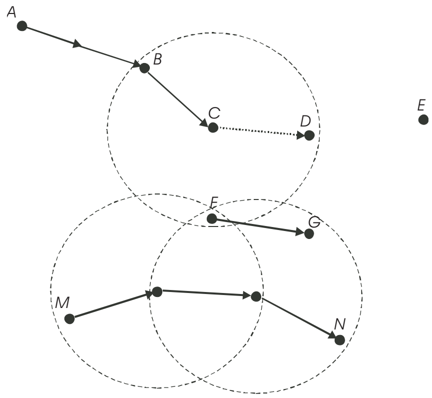

Fig. 1. An example for hidden route problem.

This paper introduces a QoS routing protocol for MANETs; the contribution are two-fold by comparing with other existing ad hoc QoS routing protocol. On the one hand, the proposed protocol takes the service differentiation MAC protocol, i.e., EDCA, into consideration. On the other hand, the hidden route problem is introduced and solved in the proposed QoS routing protocol. The problem is illustrated by an example as follows. The hidden route problem is arising at the time as the route discovery procedure of a QoS routing protocol is executed. It is because that the admission decision in a route discovery procedure considers only the local information, e.g., local capacity of the radio coverage of the node. Considering the example in Fig. 1, a route (*A*, *E*) is currently processing route discovery and there are two routes (*F*, *G*) and (*M*, *N*) that have been discovered earlier. For simplicity and convenience, assuming that the capacity is constant, said 11 units, and the bandwidth requirements of routes (*A*, *E*), (*F*, *G*), and (*M*, *N*) are 4, 2, and 6 units, respectively. When the route discovery progresses in node *C*, it should consider the capacity of its radio coverage to determine if $C \rightarrow D$ could be established or not. Within the radio coverage of node *C*, node *F* has a flow with bandwidth requirement 2 to node G. Hence the available capacity in the radio coverage of node *C* is $11 - 2 = 9$. Since the bandwidth requirement of (*A*, *E*) is 4, $C \rightarrow D$ can be established on route (*A*, *E*). However, the establishment of $C \rightarrow D$ will cause the bandwidth violation for route (*F*, *G*). It is because that there are three flows in the radio coverage of node *F*, the bandwidth for route (*F*, *G*) remains $11-4-6-2=-1$, which is not sufficient apparently.

In the rest of the paper is organized as follows. Section 2 reviews two MAC layer protocols, DCF and EDCA. In Section 3, the proposed routing protocol is presented. In Section 4, the performance of the proposed protocol is evaluated and compared with other existing routing protocols. Section 5 concludes the paper.

2. DCF and EDCA

In DCF, a mobile station that intends to transmit a packet first senses the channel. If the channel is idle for a time period of DCF interframe space (DIFS), it can immediately start transmission. Otherwise, it generates a backoff counter. The counter starts decrement if the channel is sensed idle for a time period of DIFS. Then the counter continues to decrease until the channel is busy or the counter counts down to zero. If the channel is busy, the decrement will pause and resume after another idle time period of DIFS. When the counter counts down to zero, the mobile station starts transmission. In order to avoid channel capture, a mobile station has to wait a random backoff time between two consecutive packet transmissions, even if the channel is idle for a time period of DIFS.

The backoff counter is randomly assigned a value from the range [0, CW 1], where CW is the contention window. Initially, let CW=CW$_{min}$, the minimum contention window. When the transmission (or retransmission) fails, the value of CW is doubled until it reaches the maximum CW$_{max}$=2^{m}CW$_{min}$, where m is called the *maximum backoff stage*.

DCF employs two access mechanisms for packet transmission. One is two-way handshaking and the other is four-way handshaking. For the former, an ACK (acknowledgement) message is used to indicate that the transmitted packet has been correctly received by the destination station. For the later, an RTS (request-to-send) message is first sent by the source station. When the destination station receives the RTS, it replies a CTS (clear-to-send) message. After receiving the CTS message, the source station is allowed to transmit a packet. Finally, the destination station informs the source station of a successful transmission by replying an ACK message.

RTS and CTS messages carry information about the identifiers of the source and destination stations and the duration for transmitting the packet. Once hearing the RTS or CTS message, any other station will update its NAV (network allocation vector), which records the duration when the channel is busy, and defer its access to the channel.

Four-way handshaking mechanism is optional for avoiding hidden terminal problems and alleviating collision time when the packet size is large. In the IEEE 802.11 standard, the four-way handshaking is used only when the size of transmitted packet is longer than a predefined length, i.e., *RTSThreshold*. If the transmitted packet is larger than the threshold, the four-way handshaking mechanism will be initiated. Instead, if the packet size is equal to or less than the threshold, the two-way handshaking mechanism will be initiated.

EDCA, which is an enhanced version of DCF, can provide a distributed access mechanism to support service differentiation in IEEE 802.11. EDCA introduces the concept of access categories (ACs). Traffic classes with different ACs utilize distinct values of CW$_{min}$, CW$_{max}$, and arbitration interframe spacing number (AIFSN) to contend the channel. There are four ACs specified in IEEE 802.11e as shown in Table I, where the 802.11b physical layer [2] is used.

EDCA requires that a mobile station has to wait a time period of AIFS, instead of DIFS, before transmitting a packet or generating a backoff counter. Let T_{AIFS} and T_{SIFS} denote the lengths of AIFS and short IFS (SIFS), respectively. T_{AIFS} is computed as follows: $T_{AIFS} = T_{SIFS} + \text{AIFSN} \times \delta$, where

AIFSN ≥ 1 and δ is the length of a time slot. A traffic class with smaller AIFSN has smaller T_{AIFS} and hence has a higher probability of seizing the channel.

3. The Proposed QoS Routing Protocol

For simplicity and convenience, we assume that there are three traffic classes, which is voice, video and best-effort, in the system. That is, the MAC layer is associated with three ACs. Voice, video, and best effort traffic classes adopt AC_3, AC_2 and AC_0 respectively, as shown in Table I, for contending the channel access. It is noted that the system can have more than three traffic classes, which can be achieved by specifying additional usages in the headers of corresponding control packets.

In this section, we propose a hidden route aware QoS routing (HQR for short) protocol to discover a new route with QoS guarantees and avoid the hidden route problem. we first describe the neighborhood maintenance procedure, which is recorded in each mobile node to maintain a neighboring list of other nodes in its neighborhood. Second, we describe the route discovery procedure which is used to discover a route for a source-destination transmission pair. Third, we present the QoS violation detection procedure. The QoS violation of an existing route is caused by node mobility, node failure, or QoS violation. Finally, we describe the route maintenance procedure, which is used to re-construct a route when the QoS violation of an existing route is detected.

3.1 Neighborhood Maintenance Procedure

Mobile nodes exchange information by periodically broadcasts special packets, named as hello packets, to their neighboring nodes. A hello packet will not be re-broadcasted outside the neighborhood of a mobile node, i.e., the value of time to live (TTL) is 1. Each mobile node maintains a neighboring list with several entries, in which each entry records the information of one of its neighbor nodes and has the same fields with the hello packet. Whenever a mobile node receives a hello packet from one of its neighboring nodes, it creates or updates the neighboring information in the corresponding entry of its neighbor list.

The information contained in the hello packet is important and necessary since it provides local connectivity information and load conditions of one-hop and two-hop neighboring nodes. It can also be used for QoS violation detection procedure (see Section III-*C*). Most important of all, the route discovery procedure can use the information contained in the hello packet to determine if a route request should be issued or not and avoid the hidden route problem.

3.2 Route Discovery Procedure

When a source node intends to establish a route, it first checks if the available capacity and delay are satisfied in its radio coverage. Second, it checks if the QoS requirements of existing routes are violated by the newly route. This is done by inspecting the information of its neighboring list. If both verifications are positive, it broadcasts QoS route request (QRREQ) to its neighbors. Otherwise, it simply drops the QRREQ. Upon receiving a QRREQ packet, each neighbor excepting the destination node repeats the same processes, i.e., broadcasting if the verifications are positive. A reverse path will be established by the repeated processes, as depicted in Fig. 2(a). If the destination receives a QRREQ packet, it sends a QoS route reply (QRREP) back to the source node along the reverse path and a corresponding forward path is established. Each node along the reverse path sends delay update control packets to the nodes that lie on any existing flow, as depicted as Fig. 2(b). The delay update control packet is used to update the residual delay of an existing route. The additional delay is caused by the newly discovering route. In Fig. 2(c), a complete route for (*S*, *D*) is shown and other reverse paths that do not receive QRREP packets will be ignored as timers are expired.

3.3 QoS Violation Detection Procedure

The QoS violation detection procedure is executed in nodes that lie on any existing route to detect whether the QoS of an existing route is violated or not. The reasons of route violation may be caused by node mobility, node failure, or QoS violation of a route. When a node detects the violation, a special QRREP packet is sent to the source node of the route so that the source node can execute the route maintenance procedure which is used to repair a route with QoS violation and will be described in the next section.

There are two QoS violation detection mechanisms: neighbor detection scheme and timer scheme. In neighbor detection scheme, when a node does not receive the hello packet from a neighbor node several times, the neighbor node is regarded as defected one. Hence, all routes which use the node as intermediate node are considered disconnected between sources and destination nodes.

In the timer scheme, each node designates a timer for the routes which use it as an intermediate node, in which the threshold of the timer may be the maximum tolerable delay for an application. Each node monitors the arriving data packets and updates the timer over time. When the timer is expired, the QoS violation is detected.

3.4 Route Maintenance Procedure

Route maintenance procedure is used to repair a route when the QoS violation is detected. The common method for route maintenance is based on rerouting [5]. If the QoS violation of a route is detected, the source node of the route can simply reinitiate the route discovery procedure to establish a new route to the destination. Although the rerouting takes only a message round trip time to reestablish the route along a new feasible path, some literature [5], [8] proposed redundancy path mechanism to reduce the jitter in the QoS provision as much as possible. The proposed routing protocol can use either one of the methods as its route maintenance procedure. There are different tradeoffs among different route maintenance procedures. The details and tradeoffs among these methods

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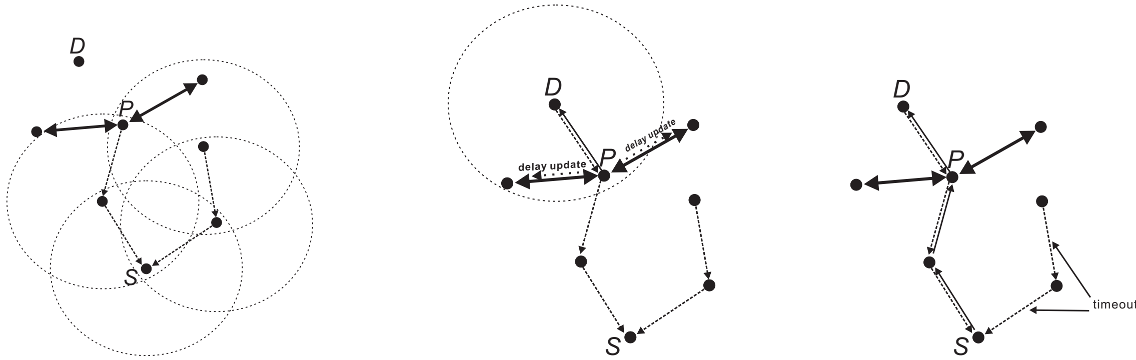

(a) Reverse path establishment. (b) Forward path establishment. (c) Complete route.

Fig. 2. An example for route discovery procedure.

are not discussed here and can refer to [5] and [6]. In this paper, route maintenance procedure is based on rerouting.

4. Simulation Results

In this section, we first demonstrate the performance impact caused by the hidden route problem via a simple experiment by using the ns-2 simulator. Second, the proposed HQR protocol and two routing protocols, AQOR [12] and AODV [9], are also simulated by using the ns-2 simulator to compare the performance of real-time flows (i.e., video flows and voice flows). AQOR is on-demand and has similar bandwidth and delay estimation methods, as compared with HQR. However, AQOR may suffer from the hidden route problem, while determining QoS routes. On the other hand, although AODV is also on-demand, it determines minimum-hop routes without QoS guaranteed. The purpose of simulating AODV is to demonstrate the difference between QoS routing protocols and non-QoS routing protocols. DCF and EDCA are also simulated for comparison.

Third, we compare the performance impact caused by the MAC layer protocol. In particular, we show the performance comparison between EDCA and DCF. Finally, we show the performance comparison for the three routing protocols described above when node mobility is considered.

In the following simulation, the radio coverage of each node is assumed a circle of radius 250 m. The underlying physical layer adopted is the IEEE 802.11b [2] where the channel bit rate is assumed 11 Mbps. The two-way handshaking mechanism is used to transmitting real-time packets.

4.1 Impact of the Hidden Route Problem

We simulate a simple experiment to show the QoS violations of existing flows caused by the hidden route problem. The simulation topology is shown in Fig. 1, where $C \rightarrow D$ and $D \rightarrow E$ are constructed as one-hop nodes in $A \rightarrow\rightarrow E$. The routes $M \rightarrow\rightarrow O$, $F \rightarrow G$ and $A \rightarrow\rightarrow E$ are associated with constant bit rate flows, where the data rates are 6.3 Mbps, 1.7 Mbps and 4.8 Mbps, respectively. The payload sizes for these three flows are all fixed as 1500 bytes. Fig. 3 (Fig. 4) shows the throughput (average end-to-end delay) for $M \rightarrow\rightarrow N$, $F \rightarrow G$ and $A \rightarrow\rightarrow E$, respectively. The routes $M \rightarrow\rightarrow N$, $F \rightarrow G$ and $A \rightarrow\rightarrow E$ start their flows at 5 second, 20 second and 35 second. It can be observed from Fig. 3 that the bandwidth requirement of $F \rightarrow G$ is violated when $A \rightarrow\rightarrow E$ starts its flow transmissions (i.e., after 35 second). Also, the average end-to-end delay of $F \rightarrow G$ has high fluctuation when $A \rightarrow\rightarrow E$ starts its flow transmissions, as depicted in Fig. 4. The reason for the performance violation is that the bandwidth consumption of $F \rightarrow G$ is 6.3+1.7+4.8=12.8 Mbps, which violates the capacity, 11 Mbps.

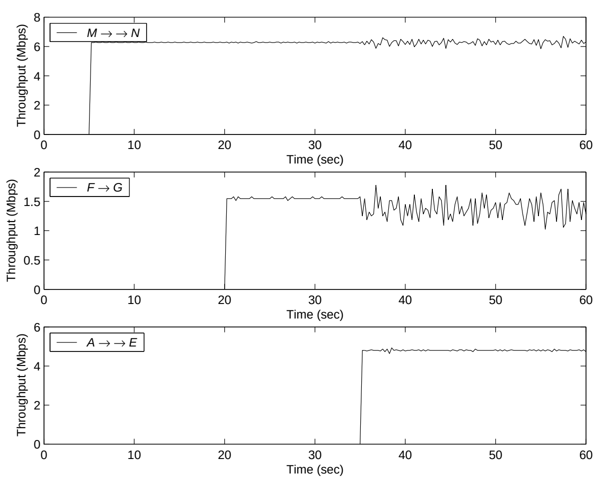

Fig. 3. Throughput violation caused by the hidden route problem.

4.2 Performance Comparison

Three criteria: average end-to-end delay, packet delivery ratio and routing overhead are adopted for performance evaluation of the three routing protocols. The average end-to-end delay is the average time length required to transmit a data packet from a (source) node to another (destination) node. The packet delivery ratio is the ratio of the number of data packets received to the number of data packets transmitted. The routing overhead is the ratio of the number of control

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packets transmitted to the number of data packets received. The number of data (control) packets transmitted increases by

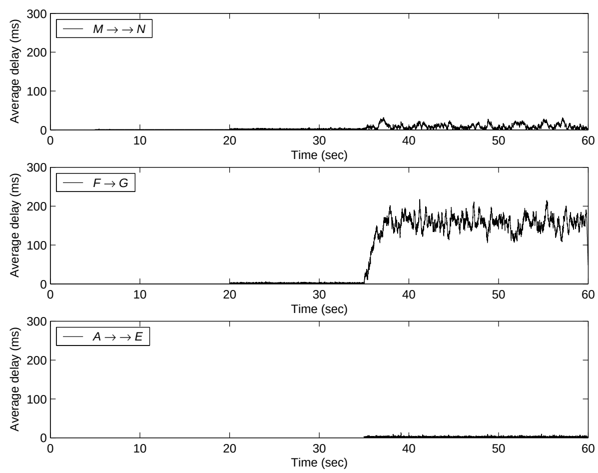

Fig. 4. Delay violation caused by the hidden route problem.

one whenever a data (control) packet is transmitted through the MAC layer. The number of data packets received increases by one whenever a destination node receives a data packet.

The network topology in the simulation is randomly generated in a $1000 \times 1000\ m^2$ region, in which fifty nodes are spread out. Traffic characteristics of voice and video flows are listed in Table II. Scenarios used in the simulation are listed in Table III where their traffic loads are increasing. In each scenario, pairs of source and destination nodes are randomly selected. Twenty-five runs are simulated and their simulation results are averaged.

Fig. 5 (Fig. 6) compares the performance of HQR, AQOR and AODV where the MAC layer protocol used is DCF (EDCA). The average end-to-end delay, packet delivery ratio and routing overhead for voice and video packets versus the traffic load are shown in Fig. 5(a) (Fig. 6(a)), Fig. 5(b) (Fig. 6(b)) and Fig. 5(c) (Fig. 6(c)), respectively. It can be observed from Fig. 5(a) (Fig. 6(a)) and Fig. 5(b) (Fig. 6(b)) that AODV is not suitable for transmitting real-time packets because of high average end-to-end delay and low packet delivery ratio. Since HQR has a lower average end-to-end delay and a higher packet delivery ratio than AQOR and AODV in all eight scenarios, it can guarantee QoS better than the other two.

On the other hand, Fig. 5(c) (Fig. 6(c)) exhibits that HQR has a higher routing overhead than AODV in scenario 1 to scenario 6. The reason is that more control overheads are inevitably involved in determining QoS routes. However, when the traffic load increases (in scenario 7 and scenario 8), HQR generates fewer overheads than AODV. Now that AODV is not designed for constructing QoS routes, routes determined by it may violate QoS requirements as the traffic load is heavy. In the simulation, route recovery for AODV is required when QoS violation happens.

Fig. 5(c) (Fig. 6(c)) also exhibits that HQR has a higher routing overhead than AQOR in scenario 1 to scenario 4. This is because additional control packets are needed in HQR to update residual tolerable delays. However, when the traffic load increases (in scenario 5 to scenario 8), AQOR generates more overheads than HQR. The reason is that the hidden route problem is more serious to AQOR as the traffic load becomes heavier. So, AQOR needs to generate more control packets for route recovery.

5. Conclusion

In this paper, a new problem called the hidden route problem was introduced, which may happen when QoS routes are to be determined. A new QoS routing protocol called HQR was proposed which can determine routes with bandwidth and average end-to-end delay guaranteed and avoid the hidden route problem at the same time. Three routing protocols, i.e., AODV, AQOR and HQR, with mobility and without mobility were simulated for performance comparison. Two MAC layer protocols, i.e., DCF and EDCA, were also simulated for comparison. The following can be drawn from simulation results.

- The throughput requirement and delay requirement of an existing flow may violated due to the hidden route problem.
- HQR has a lower average end-to-end delay and a higher packet delivery ratio than AODV and AQOR. That is, HQR can provide a better QoS guarantee.
- Compared with AODV and AQOR, HQR has a higher routing overhead as the traffic load is light and a lower routing overhead as the traffic load is heavy.

Since QoS multicasting protocols determine multiple QoS routes to different destination nodes simultaneously, they may suffer from the hidden route problem even if no routes were built earlier. As observed from our simulation, the hidden route problem may cause higher average end-to-end delay and lower packet delivery ratio. Hence, how to design a QoS multicasting protocol that can avoid the hidden route problem is one of our further research topics.

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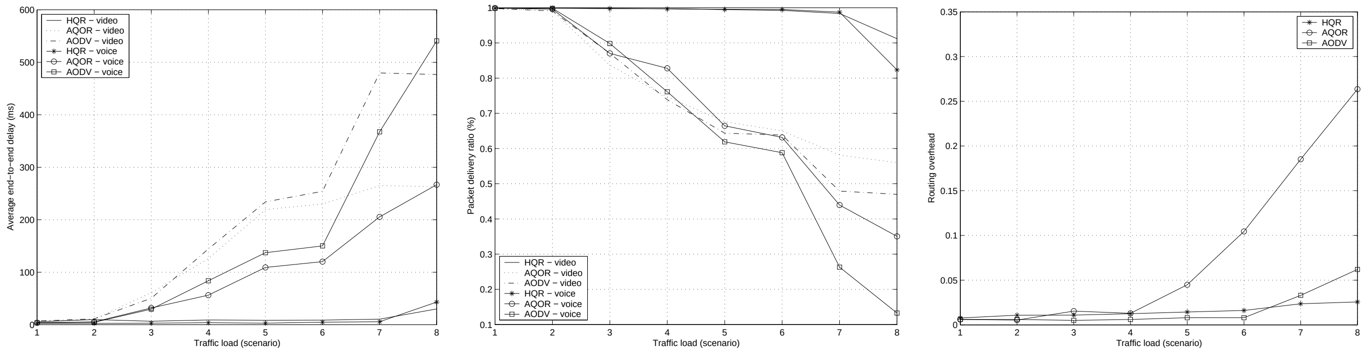
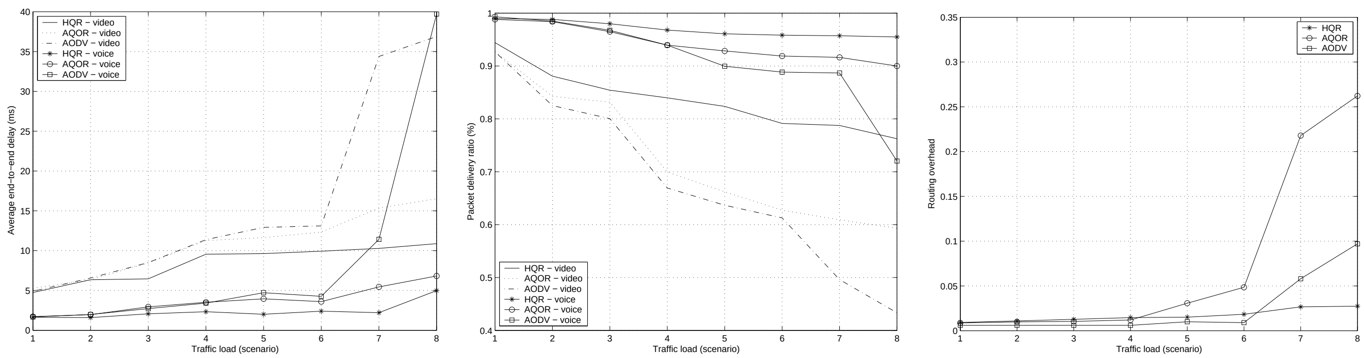


(a) (b) (c)

Fig. 5. Performance comparison based on DCF. (a) Average end-to-end delay. (b) Packet delivery ratio. (c) Routing overhead.



(a) (b) (c)

Fig. 6. Performance comparison based on EDCA. (a) Average end-to-end delay. (b) Packet delivery ratio. (c) Routing overhead.

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