QoS Routing in Mobile Ad hoc Networks Based on the Enhanced Distributed Coordination Function

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***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 coordination function (EDCF), 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 find 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.

I. 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 form 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 EDCF, to support service differentiation in the MAC layer [3]. EDCF is an extension of existing distributed coordination function (DCF) [1] which is based on carrier sense multiple access/collision avoidance (CSMA/CA). EDCF 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 EDCF will be presented in Section II.

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 EDCF, 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 from the hidden route problem in the network layer.

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., EDCF, 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.

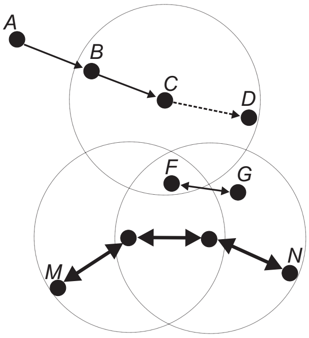


Fig. 1. An example for hidden route problem.

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 II reviews two MAC layer protocols DCF and EDCF. In Section III, the proposed routing protocol is presented. In Section IV, the performance of the proposed protocol is evaluated and compared with other existing routing protocol. Section V concludes the paper.

II. DCF AND EDCF

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=CWmin, the minimum contention window. When the transmission (or retransmission) fails, the value of CW is doubled until it reaches the maximum $\mathrm{CW}_{max}=2^m\mathrm{CW}_{min}$, 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.

EDCF, which is an enhanced version of DCF, can provide a distributed access mechanism to support service differentiation in IEEE 802.11. EDCF 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.

EDCF 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 TAIFS and TSIFS denote the lengths of AIFS and short IFS (SIFS), respectively. TAIFS is computed as follows: $T_{AIFS} = T_{SIFS} + \mathrm{AIFSN} \times \delta$, 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.

III. 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

Table I. Four ACs specified in IEEE 802.11e

	AC_0	AC_1	AC_2	AC_3
Values of AIFSN	2	1	1	1
Values of CW_{min}	32	32	16	8
Values of CW_{max}	1024	1024	32	16

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 first describe the neighborhood maintenance procedure, which is recorded in each mobile node to maintain a neighbor 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 dissatisfaction. Finally, we describe the route maintenance procedure, which is used to re-construct an existing route when the QoS violation of the route is detected.

A. Neighborhood Maintenance Procedure

Mobile nodes exchange information by periodically broadcasts special packets, named as hello packets, to their neighbor 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 neighbor 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 neighbor nodes, it creates or updates the neighbor 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 neighbor 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.

B. 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 satisfactions of existing routes is violated by the newly route. This is done by inspecting the information of its neighbor 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 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.

C. 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 dissatisfaction 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 dissatisfaction 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.

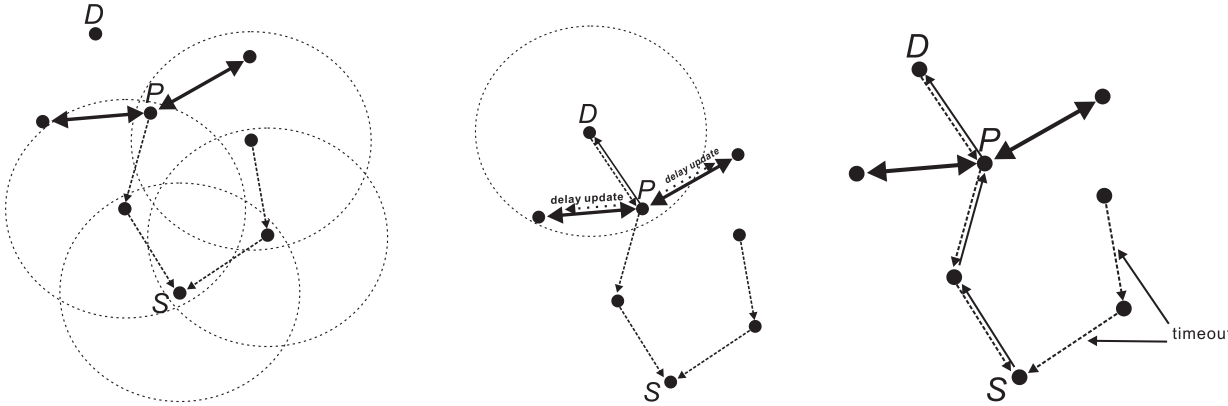
In the timer scheme, each node designates a timer for the routes which use it as an intermediate node, in which the threshold of the timer may be the maximum application tolerable delay. Each node monitors the arriving data packets and updates the timer over time. When the timer is timeout, the QoS violation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

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

IV. Performance Evaluation

We have simulated the proposed routing protocol via the ns-2 simulator [13]. The AQOR protocol described in [12] is also simulated via the ns-2 simulator for performance comparison. In addition, we also simulate a non-QoS routing protocol



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

Fig. 2. Route discovery procedure.

for comparison, which is called ad hoc on-demand distance-vector (AODV) protocol. Three performance criteria are used to evaluate the performance of these three protocols: packet delivery ratio, average end-to-end delay, and routing overhead. The criteria are defined as follows.

$$\text{packet delivery ratio} = \frac{\text{number of received data packets}}{\text{number of transmitted data packets}}$$

$$\text{average end-to-end delay} = \sum_{\text{for all packets}} E[\text{packet delay}]$$

$$\text{routing overhead} = \frac{\text{number of transmitted control packets}}{\text{number of received data packets}}$$

The number of transmitted control packets (or data packets) is counted once when a packet is transmitted in the MAC layer. The number of received data packets is counted once when a data packet is received by a destination node.

The network topology in the simulation is randomly generated in a 1000×1000 m^2 region, in which fifty mobile nodes are randomly placed. The transmission range of a mobile node is fixed and the range is a circle with the radius 250 m. The underlying physical layer we adopt is the IEEE 802.11b standard [2] and the channel bit rate is assumed to be 11 Mbps where multi-rate capability is not supported [1].

We have three traffic classes in the simulation: voice, video and best effort. The traffic characteristics of voice and video traffic classes are shown in Table II. It is noted that the minimum required bandwidths for voice and video classes are set to be equivalent to the bit rates.

The traffic load used in the simulation are detailed in Table III, in which the traffic load is heavier as the number of scenario is larger. Fig. 3 shows the packet delivery ratio of real-time packets versus the traffic load. As seen form Fig. 3, it is clear that AODV protocol is not suitable for transmitting real-time packets since the packet delivery ratio is less than AQOR and the proposed protocols for both video and voice flows.

Table II. Traffic Characteristics of Real-Time Traffic Class

	Voice	Video
Codec algorithm	G.729	H.263
Average packet inter-arrival time (ms)	20	40
Payload length (byte)	20	500
Bit rate (Kbps)	8	120
Minimum required bandwidth (Kbps)	8	120
Maximum delay toleration (ms)	70	170

Table III. Traffic Load Used in the Simulation

	Number of voice flows	Number of video flows	Number of best effort flows
Scenario 1	6	2	6
Scenario 2	8	4	8
Scenario 3	10	6	10
Scenario 4	12	8	12
Scenario 5	14	10	14
Scenario 6	16	12	16
Scenario 7	18	14	18
Scenario 8	20	16	20

The average end-to-end delays of real-time packets versus the traffic load is shown in Fig. 4. The average end-to-end delay of both video and voice flows in AODV and AQOR protocols are more larger than the one of the proposed protocol in all scenarios.

Finally, we show the routing overheads of these three protocols in Fig. 5. There is a tradeoff between routing overhead and QoS satisfaction. As seen from Fig. 5, the overhead of the proposed protocol (AQOR protocol) is higher than AODV protocol from scenario 1 to scenario 6 (in all scenarios). In addition, the overhead of the proposed protocol is higher than AQOR protocol from scenario 1 to scenario 4. This is because that the delay update control packets are issued to update the QoS information of existing routes. From scenario 5 to scenario 8 in Fig. 5, the routing overhead of AQOR protocol is more larger than the proposed one. The reason is that

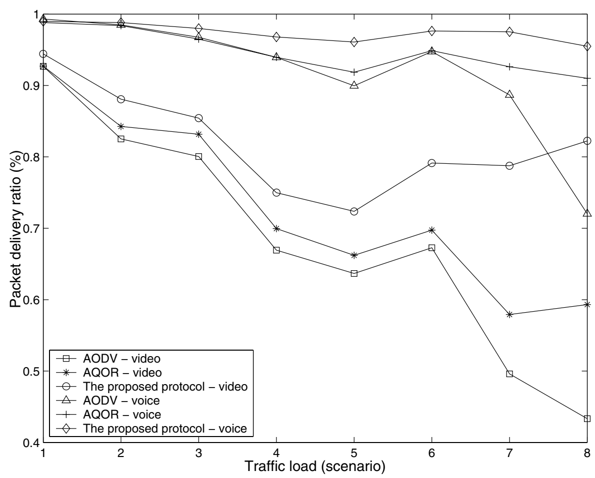


Fig. 3. Packet delivery ratio of real-time packets vs. Traffic load.

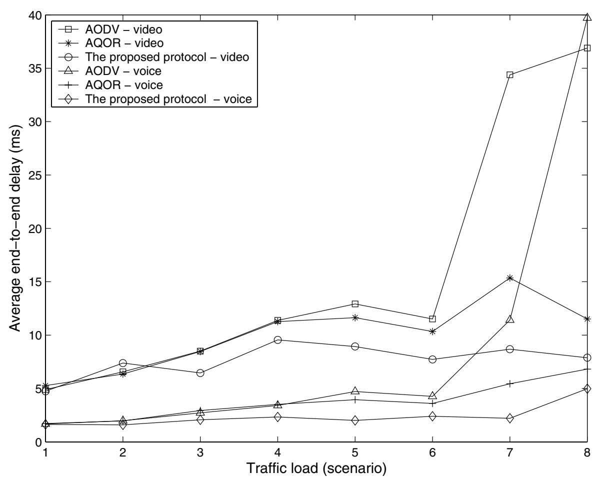


Fig. 4. Average end-to-end delay of real-time packets vs. Traffic load.

the hidden route problem is incurring as the traffic load is increasing. In scenario 7 and scenario 8, the overhead of the proposed protocol is less than AODV protocol. Since AODV protocol is not designed for finding QoS routes, the probability that the finding routes are not suitable for multimedia services will be high in heavy load. Hence, reconstructing routes for multimedia services will cause additional control overhead.

V. CONCLUSION

In this paper, we addressed on the problem in finding routes with QoS guarantees for multimedia services in MANETs. The MAC layer we adopt was a new distributed MAC protocol, i.e., EDCF, that can support service differentiation. The procedures of the proposed protocol such as neighborhood maintenance, route discovery, QoS violation detection, and route maintenance were presented in this paper. A problem, called hidden route problem, was introduced and solved in the proposed QoS routing protocol. We conducted realistic traffic patterns, e.g., G.729 audio and H.263 video, in our simulation environment. The performance metrics such as packet delivery

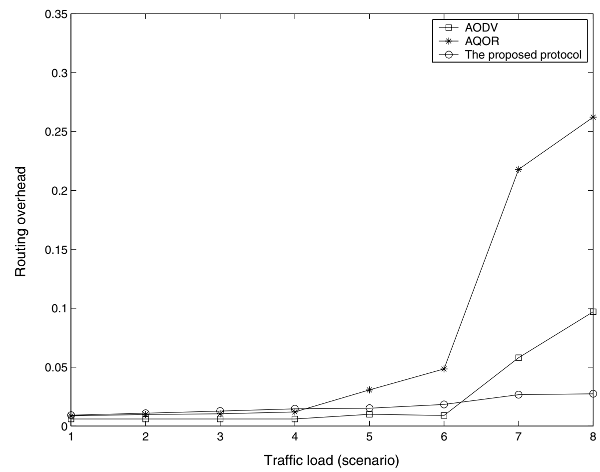


Fig. 5. Routing overhead vs. Traffic load.

ratio and average end-to-end delay outperformed than AQOR protocol with the sacrifice of routing overhead under light load conditions.

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