Providing QoS Guarantees in Ad Hoc Networks through EDCA with Resource Reservation

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Abstract

As the use of WLANs based on IEEE 802.11 increase, the need for QoS becomes more obvious. The upcoming IEEE 802.11e aims at providing QoS, but its contention-based medium access mechanism *enhanced distributed channel access* (EDCA), provides only service differentiation, i.e. soft QoS. In order to provide hard QoS, we have proposed an extension called *EDCA with resource reservation* (EDCA/RR), which enhances EDCA by offering also hard QoS through resource reservation. This report focuses on EDCA/RR with the aim to enhance the scheme further in single-hop scenarios but also to present an idea of how to extend the scheme to be useful also in multi-hop ad hoc networks.

1 Introduction

The widespread use of portable devices equipped with *wireless local area network* (WLAN)-capability is likely to increase the popularity of ad hoc networks. As the WLAN technique continues to grow and mature, the users expect to use the wireless network the same way as they use an ordinary personal computer connected to a *local area network* (LAN). Thus, the users want to have the possibility to use the same demanding applications as they run on their personal computers; e.g. to see and talk to friends using an instant messaging program.

To meet with such demands and support multimedia applications with *quality of service* (QoS) requirements, the upcoming IEEE 802.11e standard [1] introduces the new *hybrid coordination function* (HCF). It is called hybrid because it has both a contention-based and a contention-free medium access method in a single medium access protocol. The contention-based *enhanced distributed channel access* (EDCA) provides QoS by delivering traffic based on differentiating user priorities while the contention-free *HCF controlled channel access* (HCCA) provides QoS by allowing for reservation of transmission time.

Although the HCCA is an important enhancement that aims at providing hard QoS in WLANs, it is the EDCA that has received most attention so far, and it is possible that EDCA's destiny will be similar to the one of its predecessor DCF, i.e. it will be implemented by the majority of the vendors, whereas the HCCA might be somewhat neglected just as the PCF - despite the fact that HCCA is a great improvement compared to its predecessor. In addition, the EDCA is a distributed channel access method and can be used in ad hoc networks while the HCCA is centralized and thus only usable in infrastructure networks. Therefore, the focus of this report lies on the EDCA.

There has been a lot of research on providing QoS to ad hoc networks. However, many of these suggest proprietary protocols - based on times division multiple access, multiple channels, etc. It is our belief that any realistic proposal must be based on the widely spread de facto standard IEEE 802.11 [2]. Hence, in this report we propose a mechanism, supporting QoS in ad hoc networks, based on IEEE 802.11 and IEEE 802.11e. Consequently, it can be integrated into existing systems without much difficulty.

The remainder of this report is organized as follows: Section 2 gives an overview of our previous work enhancing the EDCA. In Section 3 we discuss further enhancements applied to the scheme and present some ideas for extending the scheme for multi-hop networks. Finally, Section 4 concludes this report and gives some directions for future work.

2 The Original EDCA/RR

In a previous work we have enhanced the EDCA medium access mechanism to provide QoS guarantees by reserving *transmission opportunities* (TXOPs) for traffic streams with strict QoS requirements [3]. Before starting with the enhancements based on that work, it is necessary to give an introduction to our proposed scheme in order to facilitate the reading and understanding of the rest of this report. Although not named in [3], our scheme is called *EDCA with resource reservation* (EDCA/RR) in this report.

The EDCA/RR works like the EDCA as long as there is no station that needs to reserve TXOPs for its high-priority traffic stream. Once a station (sender) wishes to reserve TXOPs to be able to send traffic with strict QoS requirements, it requests admission for its traffic stream. The admission control request is not sent to any central station such as a *QoS access point* (QAP), but is handled internally within the sender by an admission control algorithm. The sender either admits or rejects its own requested traffic stream according to the admission control algorithm. At this point, we should point out that our scheme is not dependent on any specific admission control or scheduling algorithm; thus, it is possible to use any proposed enhancement (such as those presented in [4, 5, 6, 7]) to the reference design algorithms provided in the IEEE 802.11e specification (for details see [3] or [1]). However, in our EDCA/RR implementation, the reference admission control and scheduling algorithms have been used - partly because they are specified in the IEEE 802.11e specification making them widely known and giving them certain acceptance, and partly because they are relatively easy to implement.

In case the traffic stream is rejected, the sender can try to lower its QoS demands and retry. On the other hand, if the traffic stream is admitted, the sender schedules its traffic by setting the *scheduled service interval* (SI) and the *service start time* (SST) parameters. Details about the calculation of these parameters can be found in [3]. Next, the sender broadcasts an *add traffic stream* (ADDTS) request containing a *traffic specification* (TSPEC) element with information such as mean data rate, nominal frame size, SST and SI. All stations that receive the ADDTS request store the information of the sender's SST and SI, and schedule the new traffic stream exactly as the sender. This ensures that no station starts a transmission that cannot be finished before a reserved TXOP starts and thus collision-free access to the medium is offered to the streams with reserved TXOPs. In order to make sure that all stations have similar schedules, all neighbours have to unicast an ADDTS response back to the sender to acknowledge a received ADDTS request.

Every time the sender receives an ADDTS response from a neighbour, it stores the address of the neighbour. After receiving a response from all neighbours, the sender waits until the SST specified in the TSPEC element and initiates a transmission. If the time instant when all responses are received occurs later than the advertised SST, the transmission is delayed until the next TXOP. During a TXOP, the sender can transmit multiple frames but it must stop sending when the remaining time of the TXOP is less than the transmission time of another data frame plus its corresponding ACK. Once the TXOP is finished, the station waits until the next TXOP, which occurs after an SI. A station that has reserved TXOPs for a traffic stream with strict QoS requirements, is not allowed to transmit frames belonging to that stream at time instants other than during the reserved TXOPs. Of course the station is allowed to transmit frames from other traffic streams, in other ACs, by contending for access to the medium. However, these streams and other low-priority streams from other stations must ensure to finish their transmission before a TXOP starts; otherwise the contending station must backoff and the frames are not allowed to be sent until after the reserved TXOP(s).

When a transmission failure occurs during a TXOP, the station does not start a backoff procedure. Instead, it retransmits the failed frame after SIFS if there is enough time left in the TXOP to complete the transmission.

3 Enhancing the EDCA/RR

In the previous section we described EDCA/RR that works fine in a WLAN operating in ad hoc mode, i.e. in a single-hop ad hoc network where all stations are within each other's transmission range. Although single-hop ad hoc networks might be seen as limited, we must remember that the main application area for the EDCA is a WLAN and not a multi-hop ad hoc network. To give an example of the application area for single-hop ad hoc networks where our scheme can be used, we can mention network gaming where players can use their laptops to play demanding network games with each other at no cost anywhere they want; i.e. without needing to worry about (neither wired nor wireless) Internet connections. However, since providing QoS in a multi-hop ad hoc network is also desirable, besides enhancing our scheme for the single-hop case, in this report we aim at enhancing the EDCA even further such that it can be used to provide QoS guarantees in a multi-hop ad hoc network.

In this section we start by describing our solution to a problem in EDCA/RR related to hidden stations. Next we identify some problems that might occur due to mobile stations leaving and entering a network. Finally we present a conceivable solution to extend EDCA/RR such that it can be used in multi-hop ad hoc networks.

3.1 The Hidden Station Problem in EDCA/RR

In the original version of EDCA/RR, the hidden station problem was handled through the exchange of *request to send* (RTS) and *clear to send* (CTS) frames, i.e. the same way as in IEEE 802.11(e). However, this method is not sufficient since in EDCA/RR, stations hidden to a station that has reserved TXOPs can cause other problems than the well-known hidden station problem (causing collisions). Contending stations that have received a TSPEC from the reserving station do not start a transmission unless it finishes before a TXOP starts. But unfortunately,

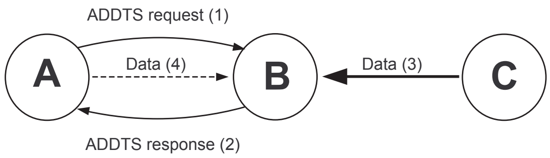

Figure 1: C is hidden from A and can start transmitting just before a A's TXOP starts.

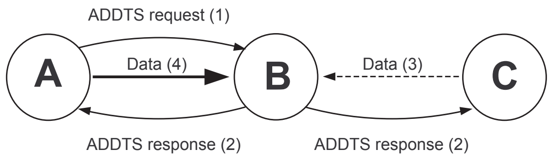

Figure 2: C is informed about the TXOP reservation of A and defers during A's TXOP.

stations hidden from the reserving station do not receive any TSPEC so they do not know when the TXOPs start. Therefore, they might start a transmission that extend across a TXOP.

To illustrate the problem with a hidden station in an ad hoc network using our scheme, suppose there are three stations in a row (see Figure 1): A, B and C, where A and B as well as B and C are within each other's transmission range but A and C cannot hear each other. Assume further that A wants to send QoS traffic to B so it has broadcasted an ADDTS request and B has replied with an ADDTS response. However, C (that is hidden from A) is unaware of A's TXOP reservation since it has not received A's ADDTS request so there is a chance that C starts transmitting just before a TXOP reserved by A is about to start. In that case a collision would occur during A's reserved TXOP meaning that A would no longer have collision-free access to the medium. In order to prevent C from transmitting just before a reserved TXOP is about to start, it must become aware of A's TXOP reservation. In other words, the reservation schedule of any sender must be known by all stations within two hops from the sender.

There are different ways of achieving this goal, i.e. to spread the TSPEC to stations outside of the reserving station's transmission range. One approach can be to rebroadcast the ADDTS request sent by the reserving station during the TXOP reservation. Hence, in our example B would rebroadcast the ADDTS request of A to let also C receive the request frame. However, there are many problems related to this approach. First, should C send an ADDTS response to B just like B has to send an ADDTS response to A? Before answering this question we must remember that there might be many stations at the same distance from A as B and C respectively (i.e. one and two hops away from A respectively). This means that if C has to respond to B then every other station two hops away from A should also respond to B because those are also hidden stations. Moreover, this procedure would continue until all stations one hop away from A rebroadcast the ADDTS request from A, and all stations two hops away from A send back an ADDTS response. Obviously, this would lead to a lot of overhead and a significant increase in the reservation delay. On the other hand, if C does not have to send a response to B, then B cannot be sure whether the rebroadcasted ADDTS request was received by C or not.

Another approach to spread the TSPEC is to let the ADDTS responses contain the TSPEC and let all stations overhear these frames (see Figure 2). This way, the TSPEC is known to all stations within two hops from the sender with no additional signaling frame and with limited increase of overhead. Thus, when B sends an ADDTS response back to A, C will hear this frame and save the information included in the TSPEC, i.e. SST and SI of A. This approach is much less complex and results in less overhead than the previous approach. However, again B cannot be sure whether the ADDTS response was received correctly by C or not. Therefore, we let reserving stations transmit special RTS/CTS frames extended to contain a TSPEC (RTS_TSPEC and CTS_TSPEC), in the beginning of a TXOP. This way, a station with an out-of-date reservation schedule has the chance to update its schedule. Although one might think that this increases the overhead too much, we must remember that the RTS_TSPEC and CTS_TSPEC frames are sent only at the beginning of a TXOP and not for every single data frame.

3.2 Leaving and Entering the Network

An important issue that needs special attention is mobility and in particular stations leaving and entering the network. For example, if a station with reserved TXOPs leaves the network, the other stations must become aware of that because otherwise they will defer from transmitting although they should not and the network capacity will be wasted. On the other hand, if a station enters a network where other stations have reserved TXOPs, it cannot start contending for access to the medium and transmit because such a transmission might collide with the transmission in a reserved TXOP.

A conceivable solution to these problems is to let the stations in the network listen for frames in the beginning of each TXOP in order to determine whether the reserved TXOPs are still in use. If there is no transmission within the first time period equal to DIFS, the TXOP is considered to be unused and can be used for transmission by other stations. This kind of situations might occur occasionally when a station with reserved TXOPs has no frames to send during certain TXOPs. If several consecutive TXOPs are determined to be unused, the receiver can ask the sender if it still has something to send. If the sender does not respond despite several attempts, the receiver and other stations can assume that the sender has left the network and delete the TXOP reservation completely. In that case, the TXOPs must be deallocated. Furthermore, possible traffic streams after the terminated stream, shall be moved back to use the unused time so that a reserved TXOP starts just after another has finished in order to avoid time gaps between two reserved TXOPs. Moving the streams is done pretty easily thanks to the distributed characteristic of EDCA/RR. There is no need for any signaling; each station performs the rescheduling itself in a distributed manner.

A station that enters the network must update its schedule before it is allowed to transmit any frame. This can be done by setting a schedule update bit in beacons or other frames exchanged during the initialization process.

3.3 QoS Provisioning in Multi-hop Ad Hoc Networks

The first goal of this report was to enhance the EDCA/RR scheme operating in single-hop ad hoc networks. In particular, we wanted to solve the problems that could occur due to hidden stations. We have achieved this goal and presented our solution above. Another goal was to propose an extension to the scheme such that it can be used to provide QoS guarantees in a multi-hop ad hoc network. For this purpose, we need an ad hoc routing protocol that can find a route between the communicating stations. In this report we assume that the routing protocol is reactive, i.e. the route discovery process is performed on-demand. Examples of two popular reactive routing protocols are *Ad hoc On-Demand Distance Vector* (AODV) [8] and *Dynamic MANET On-demand* (DYMO) [9]. During the route discovery process the source broadcasts a *route request* (RREQ) throughout the network to find the destination. When the destination receives the RREQ, it responds with a *route reply* (RREP) unicast toward the source. In this

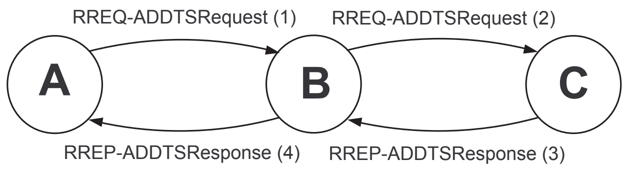

Figure 3: Simultaneous multi-hop route discovery and resource reservation.

section we present an idea of how to extend EDCA/RR in order to be able to provide QoS in a multi-hop ad hoc network.

To illustrate the idea, let us assume there are three stations in a row (see Figure 3): A, B and C, where A and B as well as B and C are within each other's transmission range but A and C cannot hear each other. Assume further that A wants to send high-priority traffic (with QoS requirements) to C.

To reserve resources along a multi-hop route, the QoS requirements of A's traffic stream must be known by the routing protocol so that it can use the requirements during the route discovery process. However, the routing protocol shall not start its route discovery process before the traffic stream has been admitted by the admission control mechanism at A's MAC sublayer. In EDCA/RR the resource reservation process (including admission control) starts when the first packet of a traffic stream with QoS requirements reaches the MAC sublayer, i.e. after it has been handled by the routing protocol at the network layer. To prevent the routing protocol searching for a route using its usual metrics (and thus not considering the QoS requirements of the traffic stream), it must be modified to co-operate with the protocol at the MAC sublayer (EDCA/RR in our case). Therefore, once the first high-priority frame of a traffic stream in station A reaches its network layer, the routing protocol must be modified to signal EDCA/RR to check whether the requested traffic stream can be admitted or not. If the traffic stream is rejected, A's application can either try to lower its QoS demands and retry or accept the fact that there are not enough resources to be reserved. Thus, in case of rejection, the MAC sublayer must inform the network layer about this fact in order to trigger the routing protocol to find a (normal, i.e. non-QoS) route to the destination. On the other hand, if the traffic is admitted, the MAC sublayer shall notify the routing protocol and send it the necessary information regarding the required QoS. Since the QoS requirements are gathered in a TSPEC, it is suitable to use the TSPEC (or possibly a part of it) in order to inform the routing protocol about the QoS requirements of the admitted traffic stream.

At this point A has determined that it has enough resources to reserve so it can start its route discovery process to search for a route that can handle its QoS requirements. Therefore, A broadcasts a RREQ-ADDTSRequest, i.e. a RREQ message including a TSPEC.

When B receives the RREQ-ADDTSRequest, its MAC sublayer handles the ADDTSRequest part of the message to check whether the traffic can be admitted or not. In case the traffic is rejected, the RREQ-ADDTSRequest will be dropped. However, although some applications need a certain minimum level of QoS for functioning, others can function despite that the QoS level is not sufficient. Therefore, in the latter case, B may broadcast an ordinary RREQ searching for a normal route to the destination. On the other hand, if the traffic is admitted, the MAC sublayer notifies the routing protocol to rebroadcast the RREQ-ADDTSRequest. Station C processes the RREP-ADDTSRequest mainly as in B. However, if the traffic is admitted, the MAC sublayer schedules the traffic stream of A and notifies the routing protocol to send a RREP-ADDTSResponse back to the source (i.e. station A).

When B receives the RREP-ADDTSResponse, its MAC sublayer handles the ADDTSResponse part of this message to schedule the traffic stream (since now the traffic stream has been admitted by all stations from the source to the destination). Then the network layer forwards the RREP-ADDTSResponse to A. Station A processes the RREP-ADDTSResponse just as in B and thus, the resource reservation is finished and the traffic stream can start transmitting during its reserved TXOPs.

4 Conclusion

This report has considered the QoS issues in ad hoc networks. In particular, the aim was to extend and enhance the previously proposed EDCA/RR scheme, which allows multimedia applications to reserve medium time according to their needs (specified in a TSPEC). The scheme has been enhanced to prevent hidden stations causing collisions during reserved TXOPs. The main idea was to spread the information about the TXOP reservation (included in a TSPEC) such that also hidden stations become aware of the reservation and thus, defer during the reserved TXOPs.

However, the EDCA/RR scheme was designed for WLANs operating in ad hoc network configuration. Although such a scheme can be useful in application areas such as network gaming, our aim was to extend it to be useful also in multi-hop ad hoc networks since these networks are expected to offer new communication possibilities. Thus, we have presented an extension to the scheme such that it can be used together with an ad hoc routing protocol to find multi-hop QoS-enabled routes between the communicating stations. Thus, a station with traffic requiring QoS will be able to reserve TXOPs for deterministic medium access along a multi-hop route to the destination. As part of our future work, this extension will be tuned and incorporated into the existing enhanced EDCA/RR implementation.

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