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# Extending EDCA with distributed resource reservation for QoS guarantees

**Ali Hamidian · Ulf Körner**

**Abstract** In this paper we describe how the contention-based medium access mechanism of 802.11e, EDCA, can be enhanced in order to allow stations to reserve medium access for their real-time applications with QoS requirements. We present our proposed scheme, which is called *EDCA with resource reservation* (EDCA/RR), and describe how it can be extended in order to be used in wireless multi-hop networks. EDCA/RR operates in a completely distributed manner and manages to provide deterministic, contention-free medium access, making it an attractive scheme for wireless networks.

**Keywords** QoS · IEEE 802.11e · EDCA · Wireless mesh and ad hoc network · Distributed resource reservation

## 1 Introduction

In this era of wireless hysteria, with new wireless technologies becoming standardized at a fast rate, we can expect an increased interest for wireless networks such as ad hoc, mesh, and sensor networks. These networks all operate in a distributed manner, independent of any infrastructure or centralized device. Providing *quality of service* (QoS) in these networks is a challenging, but yet important, task mainly because there is no central device controlling the medium access. Despite this fact, distributed approaches have shown to be much more popular to implement in today's *wireless local area networks* (WLANs). Centrally controlled medium access mechanisms are hardly implemented by the vendors. For example, the distributed medium access mechanism *distributed coordination function* (DCF), has been implemented in all products supporting 802.11 [1], while the centralized *point coordination function* (PCF) has been totally ignored. In the same way, in 802.11e [2] it is expected that the distributed technique *enhanced distributed channel access* (EDCA) will be widely spread and used while the centralized *hybrid coordination function (HCF) controlled channel access* (HCCA) might not be as successful. The most important reasons for this development are simple and fast installation for the distributed techniques and high complexity for the centralized ones. Thus, when it comes to providing QoS, we believe in a distributed approach like EDCA. However, EDCA can only provide service differentiation and not QoS guarantees. The centralized HCCA, on the other hand, can provide QoS guarantees. The motivation of our work is thus to find a distributed solution for providing QoS guarantees. In other words, we would like to combine the advantages of EDCA, being distributed, with the advantages of HCCA, being able to provide QoS guarantees through resource reservation. This combination of two attractive features results in *EDCA with resource reservation* (EDCA/RR), which extends EDCA by allowing for resource reservation with the aim of providing QoS guarantees. We strongly believe in a QoS solution that, in addition to contention-based medium access, also offers a medium access method for distributed resource reservation. Our belief is strengthened by the fact that a similar approach has already been incorporated in the *European Computer Manufacturers Association* (ECMA) standard ECMA-368 [3] for wireless personal area networks.

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When talking about QoS guarantees in this context, it should be noticed that the unpredictable and error-prone nature of a wireless medium in general, and unlicensed spectra in particular, may make it impossible to provide absolute QoS guarantees. However, in a controlled environment with no interference, it is possible to provide techniques that can provide guaranteed medium access and thus, QoS guarantees [2].

After a presentation of some related works in Sect. 2, we will give an overview of 802.11e with focus on EDCA in Sect. 3. Section 4 presents EDCA/RR and describes how the scheme can be extended to handle multi-hop scenarios. Finally, in Sect. 5 we conclude the paper and give some directions for future work.

## 2 Related work

There has been a lot of research on providing QoS in ad hoc networks. However, some of these suggest proprietary solutions—complete architectures, cross-layer frameworks and other solutions based on time division multiple access, multiple channels, etc. [4–8]. We believe that any realistic proposal must be based on the widely spread de facto 802.11-standard. Among the work that is based on the family of 802.11-standards and focus on distributed solutions, most proposed solutions provide only service differentiation and not QoS guarantees [9–12]. Below we present some related work that also aim at providing QoS guarantees through resource reservation.

Hiertz et al. present the *Distributed Reservation Request Protocol* (DRRP) [13], which is a decentralized MAC scheme based on 802.11. The scheme is similar to EDCA/RR, allowing stations to reserve access to the medium. Whenever a station (A) needs to reserve medium access for communication with another station (B), it sends a data frame containing reservation request information. Upon reception of such a reservation request, B sends an *acknowledgment* (ACK) frame that also contains information about the reservation request. The ACK frame is overheard by the neighbors of B and thus, the stations hidden to A are also informed about its reservation request. The reservation request includes information regarding the duration and repetition interval of the next transmission. All neighbors receive the reservation information by overhearing the transmissions between A and B. However, since the neighbors do not acknowledge the overheard frames and these can be lost, the reservation request is transmitted periodically so the information about its periodicity is also included in the reservation request. The main disadvantage with DRRP is that it does not have any admission control and does not aim to provide QoS guarantees. Moreover, DRRP introduces a new frame structure, which is not compatible with the existing standards.

The *Distributed end-to-end Allocation of time slots for REal-time traffic* (DARE) [14], by Carlson et al., is another decentralized MAC scheme based on 802.11. DARE allows stations to reserve periodic time slots. In particular, DARE extends the RTS/CTS reservation concept of 802.11 to a multi-hop end-to-end perspective. To reserve resources for a real-time flow over several hops, the routing protocol at the source must first find a route to the destination. The route is assumed to be symmetric. Once such a route is established, the source sends a *request-to-reserve* (RTR) frame, which includes the requested duration and periodicity of a time slot as well as the address of the destination station. When an intermediate station receives the RTR frame, it checks whether the request is conflicting with already existing reservations. If the intermediate station can make the requested reservation, it processes the RTR frame and forwards it; otherwise the request is rejected. Once the destination receives the RTR frame, it responds with a *clear-to-reserve* (CTR) frame. When the source receives the CTR frame, it can start transmitting real-time traffic at the next reserved interval. DARE is also able to repair and release unused reservations. One of the main disadvantages with DARE is the very complex and inefficient method for multiple reservations. A requested reservation may conflict with existing ones so stations might have to re-schedule (shift in time) and send messages back and forth trying to find a suitable reservation slot; this can happen at every hop! The authors mention that slot shifting becomes necessary more frequently as the number of reservations increases. Thus, new reservations can only be admitted if they can squeeze in between existing ones. Furthermore, although multi-hopping is one of the advantages of DARE, there is no mechanism for the routing protocol to consider the QoS requirements of the requested reservation during the route discovery process. Thus, the routing protocol might find a route that cannot support the requested reservation. Another disadvantage is that there is no RTS/CTS, ACK or retransmission for real-time frames (could have been optional), which could result in lost real-time frames.

In this paper we propose a mechanism that supports QoS guarantees in a WLAN operating in ad hoc mode, i.e., in a single-hop ad hoc network. The scheme is based on the existing standards 802.11 and 802.11e and consequently, it can be integrated into existing systems without much difficulty. Although single-hop ad hoc networks might be seen as limited, we must remember that the main application area for EDCA is a WLAN and not a multi-hop ad hoc or mesh 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 wired or wireless Internet connections. Furthermore,

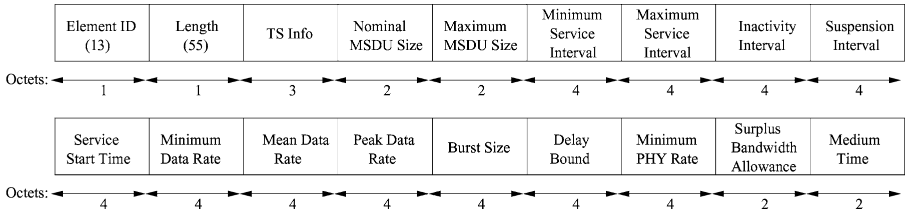

**Fig. 1** The traffic specification (TSPEC) element format

communication needs often arise between people gathered in small/limited areas, e.g., a conference room or a classroom, where all devices share the same medium. However, since providing QoS in a multi-hop ad hoc or mesh network is also desirable, besides enhancing EDCA/RR for the single-hop case, in this paper we outline a solution for multi-hop scenarios as well. In this way, a station could connect to a multi-hop mesh network and reserve medium time along a multi-hop route. An application area for such multi-hop networks with QoS support could be to let users with 802.11-capable mobile phones talk to each other for free if they are in the same area, a university campus area for example. If there is a route between the users it is indicated on the screen of the mobile phone so they can connect using the mesh network. Otherwise, they can use the cellular network as usual.

## 3 An overview of IEEE 802.11e and EDCA

The work on the 802.11e standard was motivated by the lack of support for QoS in the original 802.11 standard. The result was the new hybrid coordination function, HCF, which includes two new medium access methods: the contention-based EDCA ("enhanced DCF") and the contention-free HCCA ("enhanced PCF"). EDCA is a distributed medium access mechanism that provides prioritized QoS support by delivering traffic based on differentiating frame priorities. EDCA can be used in both ad hoc and infrastructure networks. HCCA, on the other hand, is a centralized medium access mechanism that provides parameterized QoS support by allowing for the reservation of transmission time. HCCA depends on the existence of a *QoS access point* (QAP) so it can only be used in infrastructure networks.

HCF introduces two new concepts called *transmission opportunity* (TXOP) and *traffic specification* (TSPEC). A TXOP is a time interval during which a *QoS station* (QSTA) can send as many frames as possible. These bounded time intervals were introduced to solve the problem with unknown transmission times of polled stations in PCF. A TSPEC describes the QoS characteristics of a *traffic stream* (TS) by specifying parameters such as Nominal *MAC service data unit* (MSDU) size, Minimum/Maximum *Service Interval* (SI), *Service Start Time* (SST), Mean Data Rate, and Delay Bound (see Fig. 1). Some of these parameters are set in the MAC sublayer while others are set by the application. The TSPEC was introduced to solve the problem with the inability for a station to send its QoS requirements to an *access point* (AP).

### 3.1 Enhanced Distributed Channel Access (EDCA)

To provide prioritized QoS, EDCA defines four *access categories* (ACs) for different types of traffic: AC_BK for background traffic, AC_BE for best effort traffic, AC_VI for video traffic and AC_VO for voice traffic. Thus, instead of a single transmission queue as in DCF, EDCA has four transmission queues (one per AC) that contend for TXOPs independently of each other. In order to achieve service differentiation, the contention parameters for each AC are given different values:

- CWmin/CWmax: The backoff period is calculated using the *contention window* (CW) parameter. The value of CW varies between CWmin and CWmax. It starts from CWmin and after every unsuccessful transmission it doubles until it reaches CWmax. By assigning lower values to CWmin and CWmax, an AC is given a higher priority.
- *arbitration interframe space number* (AIFSN): Before invoking a backoff or a transmission, a QSTA must defer for the duration of *arbitration interframe space* (AIFS), which is calculated using AIFSN for each AC: AIFS = SIFS + AIFSN × slot_time. By assigning lower values to AIFSN, an AC is given a higher priority.
- TXOP limit: Once a QSTA gains access to the medium it is allowed to transmit for a maximum duration equal to TXOP limit. If this parameter is set to zero, the QSTA may transmit one single frame, otherwise it is allowed to transmit multiple frames as long as the duration of transmissions does not extend beyond the limit. By assigning higher values to TXOP limit, an AC is given a higher priority.

Tables 1 and 2 show the default values for the contention parameters of each AC. As the tables show, some parameters are dependent on the *physical layer* (PHY). If the backoff timer of two or more ACs in a single QSTA counts down to zero at the same time, an internal virtual collision handler gives the AC with higher priority access to the medium, while the other AC(s) act as if there was an external collision on the medium.

**Table 1** The default EDCA parameter set for 802.11b PHY

| AC | CWmin | CWmax | AIFSN | TXOP Limit (ms) |
|---|---|---|---|---|
| AC_BK | 31 | 1023 | 7 | 0 |
| AC_BE | 31 | 1023 | 3 | 0 |
| AC_VI | 15 | 31 | 2 | 6.016 |
| AC_VO | 7 | 15 | 2 | 3.264 |

**Table 2** The default EDCA parameter set for 802.11a/802.11g PHY

| AC | CWmin | CWmax | AIFSN | TXOP Limit (ms) |
|---|---|---|---|---|
| AC_BK | 15 | 1023 | 7 | 0 |
| AC_BE | 15 | 1023 | 3 | 0 |
| AC_VI | 7 | 15 | 2 | 3.008 |
| AC_VO | 3 | 7 | 2 | 1.504 |

### 3.2 Scheduling and admission control for EDCA

In order to prevent the network to become overloaded and protect the existing data streams in the network, we need admission control to limit the amount of traffic. However, the task of implementing an admission control and scheduling scheme is not defined in the 802.11e standard and thus, left to be done by the implementers. The standard only presents guidelines for the design of a simple scheduler and *admission control unit* (ACU). Therefore, this field has become attractive to study by the research community. In [15] Gao et al. provide a survey of work on admission control for EDCA and HCCA. Some of these are proposed enhancements to the reference design. In this section, after presenting the reference design, we present some of the proposed enhancements to the reference design.

*The reference design* In 802.11e, the scheduler and ACU use the mandatory set of TSPEC parameters to decide on admission and generate a schedule:

- $\rho$: Mean Data Rate (from the negotiated TSPEC)
- L: Nominal MSDU Size (from the negotiated TSPEC)
- $SI_{max}$: Maximum Service Interval *or* D: Delay Bound
- R: Physical Transmission Rate (equal to the Minimum PHY Rate negotiated in the TSPEC or the observed PHY Rate)
- M: Maximum Allowable Size of MSDU (i.e., 2304 bytes)
- O: Overheads in time units (including interframe spaces, ACK frames and CFPoll frames)

The admission control and scheduling procedure can be described according to the following four steps:

1. Calculate SI. First the scheduler calculates the minimum $m$ of all $SI_{max}$ for all admitted streams. Then SI equals a value lower than $m$ and a submultiple of the beacon interval. For example, if the beacon interval is equal to 100 ms, SI can have one of the following values: $\{2, 4, 5, 10, 20, 25, 50\}$ ms.
2. Calculate the number of MSDUs that arrive at the mean data rate during SI. For TS $i$, where L and $\rho$ are given by the application, the number of arrived MSDUs during SI equals

$$N_i = \left\lceil \frac{SI \times \rho_i}{L_i} \right\rceil$$

3. Calculate the TXOP duration. The scheduler calculates the TXOP duration as the maximum of (a) the time to transmit $N_i$ frames at $R_i$ plus overhead and (b) the time to transmit one maximum size MSDU at $R_i$ plus overhead. This way, the scheduler ensures that the station can transmit at least one maximum-sized MSDU during a TXOP. Thus, the TXOP duration for TS $i$ equals

$$TXOP_i = \max\left(\frac{N_i \times L_i}{R_i} + O, \frac{M}{R_i} + O\right)$$

4. Admit or reject the TS. Assuming that there are $k$ admitted streams, a new stream $(k+1)$ can be admitted if it satisfies the following inequality:

$$\frac{TXOP_{k+1}}{SI} + \sum_{i=1}^{k} \frac{TXOP_i}{SI} \le \frac{T - T_{CP}}{T},$$

where $T$ is the beacon interval and $T_{CP}$ is the time used for EDCA traffic. The last term ensures that some amount of time is saved for contending low-priority streams.

It should be noticed that SI must be recalculated when a new TS with $SI_{max}$ smaller than the current SI is admitted. This will in turn lead to the recalculation of the TXOP duration based on the new value of SI.

*Proposed enhancements to the reference design* Since the reference design is based on the minimum physical rate, from which the actual physical rate could be quite different, it could be somewhat conservative and pessimistic. Therefore, there has been efforts aiming at enhancing the reference design to be more efficient. The *physical rate based admission control* (PRBAC) [16], proposed by Gao et al., considers physical rate variance due to wireless medium characteristics and station mobility. The key point of PRBAC is to use the long-term average physical rate for admission control, and the instantaneous physical rate for calculating the TXOP duration. In this way, more TSs can be admitted thanks to the more optimistic algorithm. However, being more optimistic can result in over-reserved resources and consequently to packet losses. Therefore, the authors propose a simple packet-dropping method to alleviate this problem.

Another, perhaps more severe, problem with the reference design (and PRBAC which is based on it), is that it performs well for *constant bit rate* (CBR) applications but not for *variable bit rate* (VBR) applications. The reason for this is that the reference design and PRBAC only consider the mean data rate and the mean frame size. This is not suitable for VBR traffic where the instantaneous data rate and frame size can vary a lot from the corresponding mean values. Therefore, Fan et al. present a new admission control scheme for VBR traffic in [17]. They propose a method to calculate the TXOP duration such that it can provide statistical guarantee on the packet loss probability. In [18], they extend their proposed admission control scheme by using variable SI resulting in more admitted TSs.

In [19], Ni et al. propose *fair HCF* (FHCF), which is a scheduling algorithm that aims to be fair to both CBR and VBR streams. Basically, the scheme is composed of two schedulers: the QAP scheduler and the node scheduler. The QAP scheduler estimates the queue length for each QSTA before the next SI. This estimated value is compared to the ideal queue length and gives the estimation error, which is used by the QAP scheduler to adapt the calculation of the TXOP duration. The node scheduler has to redistribute the unused reserved time to the other TSs within the QSTA.

In the current implementation of EDCA/RR, we have implemented the reference design but our scheme is not dependent on any specific algorithm. Thus, any enhanced proposal for admission control and scheduling can be used together with EDCA/RR; perhaps with some minor modifications.

## 4 EDCA with resource reservation (EDCA/RR)

In order to provide QoS guarantees, we have extended the distributed EDCA with some desired functionalities of the centralized HCCA. This combination results in EDCA/RR, which operates like EDCA for low-priority traffic from AC_BE and AC_BK but that also offers resource reservation to high-priority traffic from AC_VI and AC_VO. Thus, EDCA/RR is an enhanced and extended version of EDCA offering all its existing functionalities plus distributed resource reservation, admission control and scheduling. The distributed admission control and scheduling is realized simply by implementing the algorithms in the QSTAs instead of in the QAP only. For this idea to hold, QSTAs must broadcast their reservation requests to all neighbors instead of unicasting them to the QAP alone. This simple idea does not only provide distributed admission control and scheduling, but also makes our scheme independent of the admission control and scheduling algorithms.

A QSTA determines that it needs to reserve TXOPs for one of its high-priority TSs if the packets belonging to that stream have a *traffic stream identifier* (TSID) indicating so. In that case, when the first frame of the stream reaches the MAC sublayer, the admission control algorithm checks whether the TS can be admitted. This check is done locally within the QSTA and not by sending a message to a central device such as a QAP. In case the TS is rejected, the application can either try to lower its QoS demands or fall back to EDCA for contention-based medium access. However, if the TS can be admitted, the QSTA broadcasts an *add traffic stream* (ADDTS) request. If, for any reason, the message is lost, it will be retransmitted. In order to decrease the reservation delay, the ADDTS request is sent from a special high-priority AC, called AC_MA, used by important management frames (e.g., ADDTS requests and ADDTS responses), ARP frames and routing messages. Since this AC is not shared with data frames, the queueing delay is substantially decreased. Moreover, AC_MA has high priority since it has the same contention parameters as AC_VO except for TXOP limit, which is set to zero since there is usually no need for sending more than one management, ARP or routing message in a short time period.

The broadcasted ADDTS request contains a TSPEC element with information such as nominal MSDU size, mean data rate, SI, SST and minimum PHY rate. This information is used by the neighbors to schedule the reservation exactly as the reserving QSTA. After storing the TSPEC information, the neighbors send an ADDTS response back to the reserving QSTA. In order to prevent QSTAs two hops away from the reserving QSTA, i.e., hidden stations, to start a transmission just before a reserved TXOP is about to start and cause a collision, they must be informed about the reservation of the QSTA. In other words, the reservation schedule of any QSTA must be known by all neighbors within two hops from the reserving QSTA. Therefore, the ADDTS responses contain a TSPEC element and all QSTAs overhear these frames. So when the hidden stations overhear the ADDTS responses, they store the TSPEC information and this way, the reserving QSTA will have contention-free access to the medium. It should be mentioned that the QSTAs must operate in promiscuous mode in order to overhear a message destined to another station. This results in higher power consumption.

When the reserving QSTA receives an ADDTS response, it stores the address of the neighbor. Once it has received a response from all neighbors, the reservation procedure is over. Hence, the QSTA has contention-free and deterministic access to the medium with a duration equal to the calculated TXOP duration, starting from SST and with a period equal to SI. If the time when all responses are received has already passed the requested SST, the QSTA waits until the next TXOP to start its transmission.

During a TXOP, lost frames are handled immediately by retransmitting the frames in case the remaining time in the

TXOP is enough for the retransmission. Thus, it is not necessary to start a backoff procedure after every transmission failure.

Using this scheme, it is not difficult to handle multiple reservations. New TSs can reserve TXOPs in the same way as described before. The only difference is that the SST for the new TS is set to the end time of the last reserved TXOP in an SI. If a TS is terminated, the other TXOPs should be reordered within the SI in order to avoid time gaps between TXOPs.

### 4.1 QoS provisioning in multi-hop IEEE 802.11s mesh networks

In order to provide end-to-end QoS guarantees in a wireless, multi-hop network, we need a routing protocol that is able to find a multi-hop route between two stations. For *mobile ad hoc networks* (MANETs), there has been lots of proposed routing protocols but four of them have been developed as experimental *request for comments* (RFC) by the MANET working group within IETF. These four protocols are *Ad Hoc On Demand Distance Vector* (AODV) [20], *Dynamic Source Routing* (DSR) [21], *Optimized Link State Routing* (OLSR) [22] and *Topology Dissemination Based on Reverse-Path Forwarding* (TBRPF) [23]. Among these protocols, AODV and DSR are reactive while OLSR and TBRPF are proactive. Based on the experience gained during the development of these protocols, the MANET working group went on to standardize *Dynamic MANET On-demand* (DYMO) [24], which is reactive, and *Optimized Link State Routing version 2* (OLSRv2) [25], which is proactive. In addition, the upcoming IEEE 802.11s [26] standard for mesh networking suggests a hybrid routing protocol called *Hybrid Wireless Mesh Protocol* (HWMP).

*IEEE 802.11s* The upcoming IEEE 802.11s standard for mesh networking defines extensions to the 802.11 PHY and MAC sublayer. The purpose of the project is to provide a protocol for auto-configuring paths between APs over multi-hop topologies. The default routing protocol that is proposed to be used for this purpose is HWMP. As the name indicates it is a hybrid reactive/proactive routing protocol. The reactive part is called *Radio Metric AODV* (RM-AODV) while the proactive part is based on tree-based routing. Since there will be a reactive routing protocol, based on AODV, in the future 802.11s standard, we plan to incorporate EDCA/RR with AODV in order to provide deterministic medium access in a multi-hop ad hoc/mesh network. Later, when the standard becomes ready, it should not be difficult to combine EDCA/RR with HWMP. In fact, since EDCA/RR operates at the MAC sublayer, it should even be easier to make EDCA/RR collaborate with HWMP also operating at the MAC sublayer compared to AODV operating at the network layer. Furthermore, the fact that 802.11s is based on EDCA makes the integration of EDCA/RR into 802.11s rather simple.

*AODV* AODV is a reactive ad hoc routing protocol, where the reactive property implies that a station requests a route only when it needs one. Whenever a station determines that it needs a route to another station, it broadcasts a *route request* (RREQ) and sets a timer to wait for the reception of a *route reply* (RREP). A neighbor receiving a RREQ unicasts a RREP back to the source if it is either the destination or if it has an unexpired route to the destination. Otherwise, the neighbor rebroadcasts the RREQ. When a link break occurs, the station upstream of the break invalidates all its routes that use the broken link and broadcasts a *route error* (RERR). Upon reception of a RERR, a station invalidates possible routes to the unreachable destinations and broadcasts a new RERR to its neighbors. This process continues until the source receives a RERR. The source invalidates the listed routes and reinitiates a route discovery process if needed.

*Proposed scheme* Instead of first starting a route discovery process and then a resource reservation process, our idea is to combine the route discovery and resource reservation procedures. The advantage of this approach is that the route discovery is aware of the QoS requirements of the application so the QSTA will search for a route that fulfills those QoS requirements. Other advantages are shorter route discovery/resource reservation delay and less overhead.

When the first high-priority packet reaches the network layer, the ad hoc routing protocol checks its routing table for a route to the destination. Since this is the first packet of a high-priority TS, it must trigger a route discovery/resource reservation process by generating a *route and reservation request* (RRQ). Thus, the routing protocol must be modified not to return a route to the destination if that route is not known to support the requested QoS requirements. The RRQ message is a RREQ extended with some fields copied from the high-priority packet: frame size, data rate and priority class. These parameters are set by the application for the TSPEC and are used during the calculation of SI and TXOP duration. After creating the RRQ message, it is sent down in the protocol stack to the data link layer. The MAC sublayer starts the resource reservation procedure by checking if the new TS can be admitted. Note that EDCA/RR only checks whether to admit or reject the traffic stream—it does not reserve any TXOPs yet. The reason for this is that at this point, the station cannot know whether a (multihop) route between the source and the destination really exists or not—and even if such a route exists, the station cannot know whether the route has enough resources to be reserved or not. Each station has knowledge about the reservations of its 2-hops neighbors, but not about the reservations of those further away. Therefore, the actual resource reservation is made once the destination sends a response back to the source (after receiving a RRQ indicating that a route with enough resources exists). If the admission control fails, the application might prefer an ordinary non-QoS route (not taking into account the QoS requirements of the application) to the destination than not having any route at all. Although some applications need a certain minimum level of QoS to work properly, others can function despite that the QoS level is not sufficient. The preferred option shall be indicated by the application. Thus, if the TS is rejected, depending on the QoS requirements of the application, either it is notified to abort because there are not enough resources to reserve or the routing protocol is notified to generate a RREQ instead.

On the other hand, if the admission control is successful, the RRQ is broadcasted as usual, i.e., as if it was a normal RREQ message. A station that receives the message, stores the information about the reservation and starts the resource reservation procedure at the MAC sublayer to check whether the new TS can be admitted. Once again, if the admission control fails, depending on the QoS requirements of the application, either it is notified to abort because there are not enough resources to reserve or the routing protocol is notified to search for an ordinary non-QoS route to the destination. However, if the TS can be admitted, the station marks the status of the route as "admitted" and rebroadcasts the RRQ. In this way, the message is forwarded by all intermediate stations until it is received by the destination. The destination responds with a *route and reservation reply* (RRP), which is an ordinary RREP message extended with information about the resource reservation. This message confirms the reservation request and changes the status of the route from "admitted" to "reserved". Stations that overhear this message, will get informed about the reservation and thus refrain from transmitting during the reserved TXOPs. Upon receiving the RRP, the reserving station has deterministic contention-free access to the medium.

If any station along the route between the source and the destination cannot reserve the requested resources, the destination will never generate a RRP, which may result in some stations keeping the preliminary status of the route as "admitted". Therefore, a timer is needed to release the temporary reservations if the end-to-end reservation fails.

## 5 Conclusion

In this paper we have presented EDCA/RR, which is a medium access scheme based on EDCA, i.e., the contention-based medium access method in 802.11e. In addition to offering the functionalities of EDCA, EDCA/RR offers TSs with QoS requirements the opportunity to reserve TXOPs for deterministic and contention-free medium access. In other words, EDCA/RR extends EDCA by allowing for reservation of periodic TXOPs. The scheme uses a distributed approach for admission control, scheduling and reservation, making its implementation rather easy. Moreover, it is based on existing standards.

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