A Decentralized Reservation Scheme for IEEE 802.11 Ad Hoc Networks

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***Abstract*— As the market for *Wireless Local Area Networks (WLANs)* based on IEEE 802.11 addresses no longer only the business market but also the home user, new demands for WLANs emerge. Multimedia applications require support for *Quality of Service (QoS)*, which is addressed by the upcoming IEEE 802.11e. For the satisfaction of the home user these wireless ad hoc networks must support multihop communication. The centralized prioritizing mechanism of the *Hybrid Coordination Function (HCF)* relies on an infrastructure of *Hybrid Coordinators (HCs)* which may not be available in the home environment. Thus we provide a new decentralized reservation scheme to prioritize data in 802.11 and present simulation results.**

I. Introduction

Today's *Wireless Local Area Network (WLAN)* market is dominated by one standard of the IEEE, 802.11 [1]. 802.11 devices (*Access Points (APs)*, WLAN etc.) have become affordable for the home user. Thus WLANs face not only the requirements of plain data services but also of *Quality of Service (QoS)* sensitive applications like *Voice over IP (VoIP)*. Task Group E of the IEEE 802.11 therefore proposes prioritization mechanisms [2]. Combining QoS support and the high data rates of up to 54 Mbit/s by 802.11a [3] and 802.11g [4] at 5 GHz respectively 2.4 GHz, a replacement of the wired infrastructure becomes available. Unlike business usage of WLANs, where an infrastructure is often available, home user networks are much more depending on the support for multihop connections. Besides the usage of the *Distribution Service (DS)* in an *Extended Service Set (ESS)* with help of two or more APs 802.11 does not offer any other support for relaying functions. To achieve QoS in multihop situations, all of these APs have to include a central coordinator, otherwise time bounded service cannot be properly supported or only on a probability driven basis. As the installation of multiple central coordination instances is very unlikely in home environmental usage, we provide a new decentralized reservation mechanism.

This paper is outlined as follows. First of all we give a short introduction to 802.11 and 802.11e to understand multihop communication. Afterwards we profess a concept for a decentralized reservation scheme. Based on simulations we evaluate the approach and present our new solution. The simulations consider the 802.11a *Physical Layer (PHY)*.

II. IEEE 802.11

To give an understanding of the *Medium Access Control (MAC)* protocol of 802.11, we give a short introduction. All the details of the 802.11e are beyond the scope of this paper. See [5] for a better overview. First of all we explain 802.11. Afterwards the QoS supporting extensions of 802.11e are explained.

A. Types of Basic Service Sets (BSSs) in 802.11

802.11 describes two different kinds of BSSs. An *Independent Basic Service Set (IBSS)* is the ad hoc form of a BSS. As there is no central coordination instance in an IBSS, it uses the *Distributed Coordination Function (DCF)* as its Coordination Function (see II-B). 802.11e introduces support for QoS, thus an *QoS Independent Basic Service Set (QIBSS)* relies on the *Enhanced Distributed Coordination Function (EDCF)* defined in 802.11e (see II-C). All stations communicate directly with each other. For both IBSSs all stations must be within reception range of each other therefore.

If a central coordination instance, an AP, is available, the BSS is centrally coordinated. It is called an infrastructure based BSS. Stations must associated to the AP to participate in the communication. All traffic in this BSS is always send via the AP. Thus a station transmits every data to the AP which retransmits the data to the final destination. The final destination may either reside inside the same BSS or can be reached via the ESS. In the later case another AP receives this frame and transmits it to the desired station.

B. The 802.11 MAC protocol

802.11 defines two Coordination Functions, the decentralized DCF and the *Point Coordination Function (PCF)*, which uses a central coordination instance. If the PCF is used it alternates with the DCF.

1) The DCF: The basic 802.11 MAC protocol is the DCF based on *Carrier Sense Multiple Access (CSMA)*. After detecting that there is no other transmission in progress on the channel, 802.11 delivers *MAC Service Data*

Units (MSDUs) of arbitrary length (up to 2304 byte). For each successful reception of a frame, the receiving station immediately acknowledges the frame reception by sending an *Acknowledgment (ACK)* frame. The failure of such an ACK indicates a physical collision on the channel. *Collision Avoidance (CA)* reduces the probability of such collisions. As part of CA, before starting a transmission each station performs a backoff procedure. It has to keep sensing the channel for an additional random time after detecting the channel as being idle for a minimum duration called *Distributed Coordination Function Interframe Space (DIFS)*. The additional random time is a multiple of slots. The number of slots is determined by a random number drawn from the interval $(0, CW + 1)$. The size of the *Contention Window (CW)* doubles after each unsuccessful transmission to diminish the probability of collision of a retransmission.

2) The PCF: The PCF can only be used by an active *Point Coordinator (PC)* which typically resides inside the AP. During the *Contention Free Period (CFP)*, which may start only after a beacon frame, no stations besides the PC are allowed to transmit. Only the PC initiates frame exchanges by polling stations. Several disadvantages prevent support for QoS during the CFP.

C. The 802.11e MAC protocol

802.11e introduces support for QoS via *Hybrid Coordination Function (HCF)* and EDCF. The EDCF extends the DCF. It is part of the HCF. Thus all 802.11e stations support the HCF and EDCF. One crucial feature of 802.11e is the *Transmission Opportunity (TXOP)*. A TXOP is defined as an interval of time when a station has the right to initiate transmissions, defined by a starting time and a maximum duration. TXOPs are acquired via contention (EDCF TXOP) or granted by the *Hybrid Coordinator (HC)* via polling (polled TXOP). The duration of an EDCF TXOP is limited by a TXOPLimit distributed in beacon frames.

1) The EDCF: An QIBSS has no central coordination instance and therefore uses the EDCF. 802.11e stations consist of up to four virtual stations which represent different priorities. Each of the priority contends independently on the channel. A priority is mapped to an *Access Category (AC)*. In the *Contention Period (CP)*, each AC within the stations contends for a TXOP and independently starts a backoff after detecting the channel being idle for an *Arbitration IFS (AIFS)*, which depends on the AC. If the backoff counters of two or more parallel ACs in a single 802.11e station reach zero at the same time, two frames of different priorities are to be transmitted at the same time, which is referred to as a virtual collision. However, rather than transmitting two frames, a scheduler inside the 802.11e station resolves this virtual collision: the scheduler lets the backoff instance with highest priority transmit its frame. The other backoff instance acts as if a collision at the channel happened.

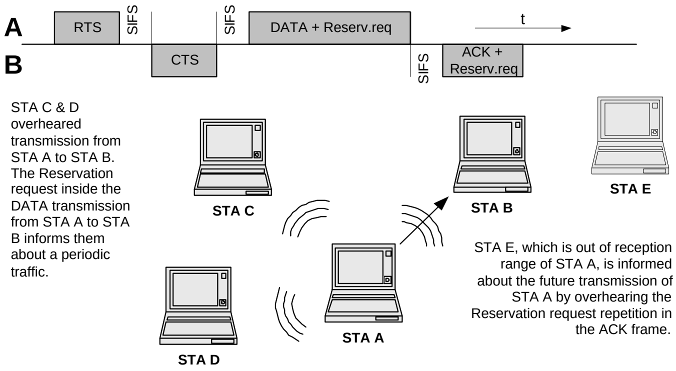

Fig. 1. A scenario consisting of five stations explains the DRRP.

2) The HCF: 802.11e introduces the HC, which works as a centralized controller for all other stations within the same *Quality of Service Basic Service Set (QBSS)*. The HC typically resides within an 802.11e AP. Since the HC is the only station in an infrastructure QBSS which does not have to perform a backoff, but can transmit at any time the channel has been idle for a duration equal to *Point (Coordination Function) Interframe Space (PIFS)* (which is equal to $25\,\mu$s for 802.11a), the HC has highest priority of all stations. It can therefore guarantee service level agreements as it has full control over the access of the channel. Unfortunately this absence of an backoff leads to high probability of collisions in situations of overlapping infrastructure QBSS when two or more HCs interfere each other. Time bounded services are then severely disturbed.

III. A decentralized reservation protocol for 802.11

As this paper focuses on multihop procedures for multimedia applications all stations are regarded to support 802.11e. Since the routing functionality is not part of the MAC, we consider that a route between the source and the destination has already been established by a higher layer functionality.

A. Introduction to DRRP

In highly load conditions 802.11 suffers from the backoff. It increases the delay and reduces throughput as collisions have to be resolved by waiting. To overcome the disadvantages of this kind of CA we propose an anticipatory method. The *Distributed Reservation Request Protocol (DRRP)* avoids collisions, as stations inform their neighboring stations about planned transmissions in the future. Fig. 1 presents an example. station B, C and D are in reception range of A. STA E is out of reception range of A. With or without usage of RTS/CTS station A transmits a frame to station B. This frame includes a reservation request. As stations C and D already sense the channel according to the Clear Channel Assessment they receive the transmission from station A and decodes the reservation information. This reservation request information is stored

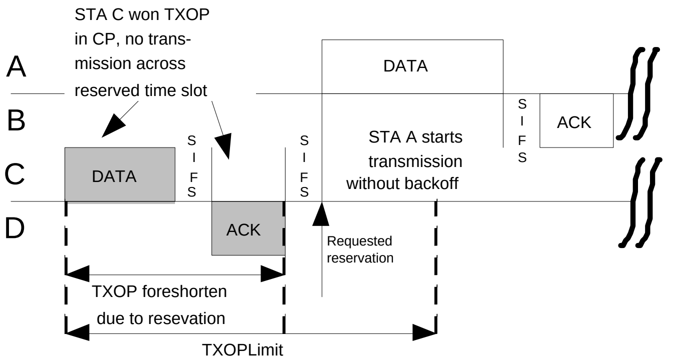

Fig. 2. station C has won a TXOP in CP. It matches the TXOP that its transmission do not interfere a following DRRP reservation.

in a local table at stations C and D. As the processing of the reservation request information is prescribed by the protocol, each station uses the table entries in the same way to refrain from interference at the scheduled reservation time. This restraint from accessing the channel is easy to implement as stations according to 802.11e already implement a function that denies them from transmitting across Target Beacon Transmission Time as an example, see Fig. 2.

B. Enhancing the reservation information

To avoid future collisions the duration until the next scheduled transmission of station A from the end of the actual transmitted frame is given. The reservation request also carries information on the duration of the next transmission. The same way the setup procedure for a Traffic Specification in 802.11e receives information about the nature of the traffic this DRRP information elements must be provided by a higher layer. Thus a station can reserve a TXOP in the future. Reserving TXOPs may even be useful for best effort traffic as it avoids collisions.

Fig. 3 presents an overview on the frame structure. Since overhearing of neighboring transmissions may fail, the possibility of a consistent reservation table in all stations is increased by including the periodicity of a reservation request. This ensures that a station refrains from channel access even if it did not receive the last reservation request but only one of its predecessors as an example. Thus the reserving station may reserve the channel for more than one TXOP in advance.

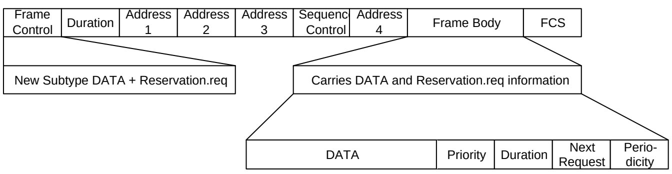

Fig. 3. The new frame structure includes the necessary reservation request elements inside the frame body. A new subtype indicates the reservation request.

As the decentralized nature of our protocol may lead to colliding reservation requests, a reservation request includes a priority. Lower priorities defer to higher priorities in situations where their reservation request overlaps. To resolve reservation conflicts each station uses its DRRP table entries. Based on these information elements the owner of the conflicting reservation requests can decide which request is to be handled first. In case of reservation requests of the same priority the older reservation request is given higher priority. This behaviour equals cell phone networks, where a handover from a neighboring cell cannot rule out existing calls in this cell. stations that reserved multiple TXOPs in advance may unsay their reservation requests by a NULL frame. Another useful aspect allows the reserving station to tear down a reserved TXOP before the end of the reserved time slot. Thus the station that initiated the reseveration can free the channel to allow other stations to use the channel again.

IV. Evaluation

A. Methodology

We use event-driven stochastic simulations to discuss the efficency of multihop procedures in 802.11. Simulation campaigns have been performed for the 802.11a PHY that allows up to 54 Mbit/s in the 5 GHz license exempt band. For delay results, we give empirical Complementary Cumulative Distribution Function of the resulting stochastic data, using the discrete Limited Relative Error algorithm that also measures the local correlations of the stochastic data [6]. By measuring local correlations, the accuracy of empirical simulation results can be estimated. All results presented in this paper are within a maximum limited relative error of 5%.

The simulations were performed using the *Wireless Access Radio Protocol 2 (WARP2)* simulation environment developed at the Chair of Communication Networks, Aachen University [7]. It is programmed in Specification and Description Language using Telelogics TAU SDL Suite (previously named SDL Design Tool). The error model used in WARP2 to accurately simulate the channel is presented in [8].

B. Results

The scenario simulated is shown in figure 4. Nine stations are placed in a grid. Only stations neighboring on a line are in reception range of each other. Along a diagonal communication is not possible but interference is still significant. Station D has set up a multihop route to station F using station E as the forwarding node. All other routes indicated by arrows are single hop routes. The offered traffic on the multihop route D-E-F is increased with every simulation. In a scenarion without the usage of DRRP station A and station G may prevent station D by own transmissions from accessing the channel because the neighborhood capture effect [9] reduces the probability for station D to grab the channel. Thus the simulated scenario

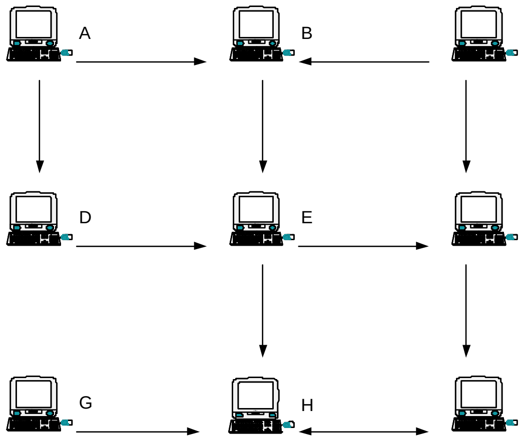

Fig. 4. The simulated scenario consists of nine stations. Station D has set up a multihop connection to station F with E as the forwarding node. All other routes carry best effort traffic.

is hard to handle when using plain 802.11 for multi-hop connections. The offered traffic on the ten single hop routes stays constant at 128 kbit/s respectively 256 kbit/s. During all simulations the QPSK-1/2 PHY mode was used. As 802.11 performs badly at small frame sizes, hence packets of 80 Byte size were used for the simulations. Thus the results can be seen as a lower bound. Also packets of 80 Byte size are a good approximation for VoIP frames [10]. The stations form a single IBSS.

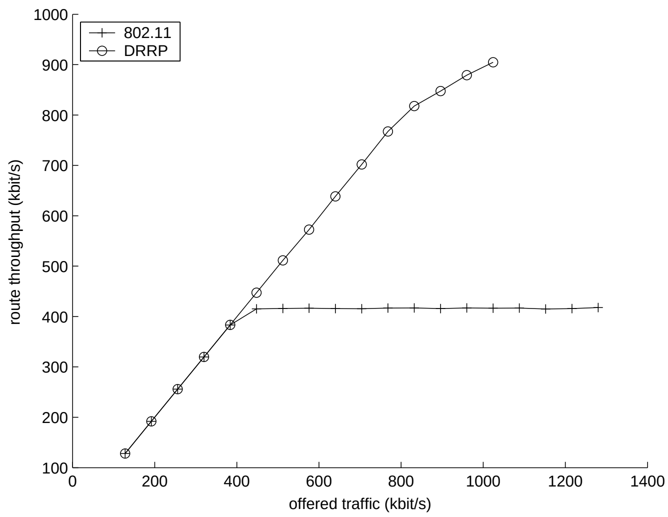

Fig. 5. Throughput on route D-E-F using DRRP compared to standard backoff procedure. To each of the ten other route 128 kbit/s traffic is offered.

Fig. 5 and Fig. 6 show the limited throughput the multihop route can achieve when the standard backoff procedure is used. In comparison to these results the DRRP achieves of course a higher throughput, as it does not share the channel with other stations. On the one hand the DRRP route does not have to share the channel with other routes in our scenario, but on the other hand unused capacity is avoided as a backoff is not included to every transmission on the DRRP route. Fig. 7 presents the *Complementary Cumulative Distribution Function (CDF)* of the delay on route D-E-F. At the same offered traffic on the multihop route and the same background traffic, legacy 802.11 has a high delay compared to DRRP.

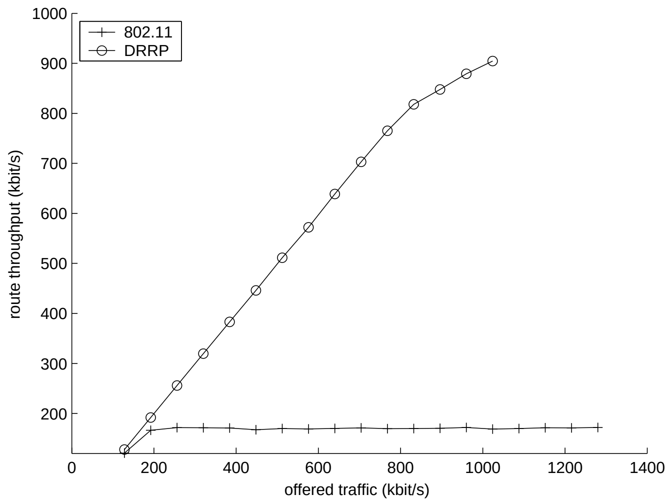

Fig. 6. Throughput on route D-E-F using DRRP compared to standard backoff procedure. To each of the ten other route 256 kbit/s traffic is offered.

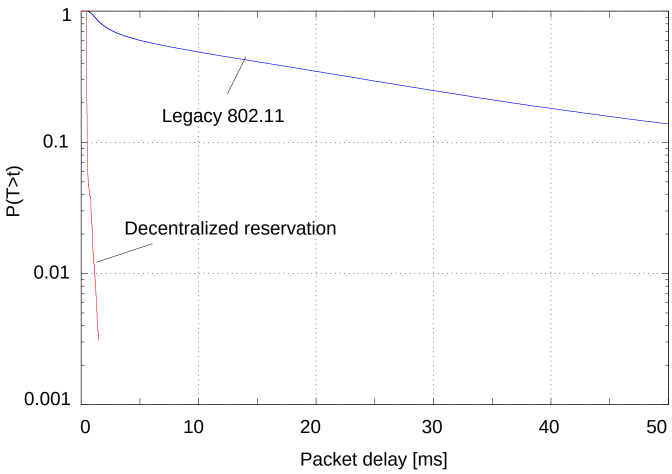

Fig. 7. Complementary distribution function of the packet delay on route D-E-F when DRRP or legacy 802.11 is used. 256 kbit/s traffic is offered to all other routes.

Comparing Fig. 8 and Fig. 9 it can be seen, that with DRRP the multihop route is not much affected by the background single-hop connections. Even if the offered background traffic is increased, the delay of the DRRP stays very low. Only at the saturation load of the multi-hop connection (of around 800 kbit/s) the delay increases to a much higher level.

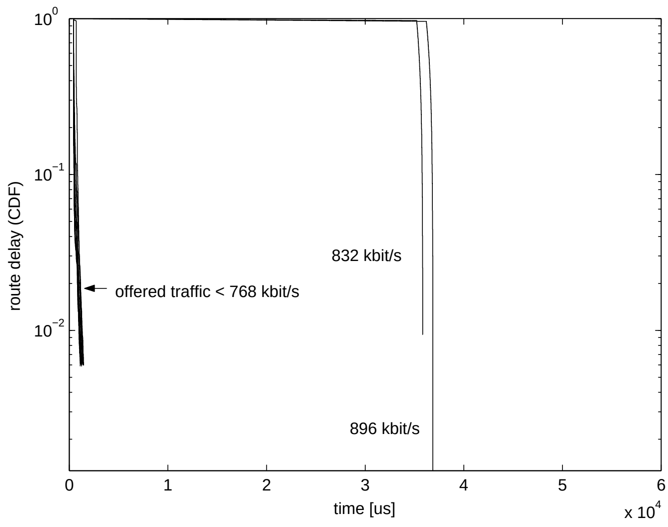

Fig. 8. Complementary distribution function of the packet delay on route D-E-F using DRRP. 128 kbit/s traffic is offered to all other routes.

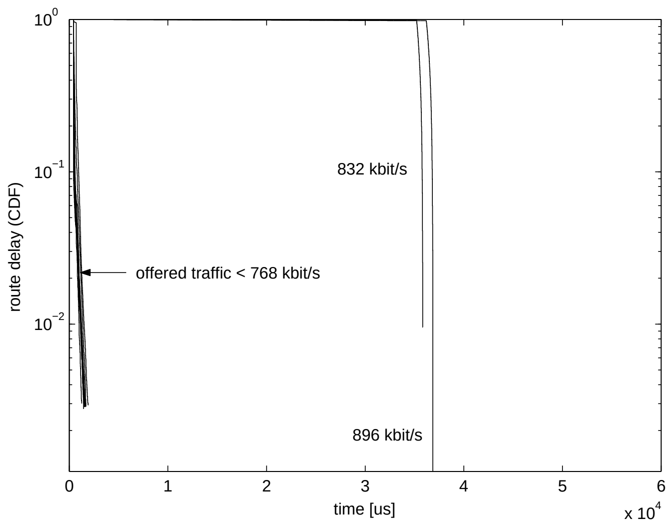

Fig. 9. Complementary distribution function of the packet delay on route D-E-F using DRRP. 256 kbit/s traffic is offered to all other routes.

V. Conclusions

Our new proposal avoids time consuming, delay increasing and throughput decreasing collisions on the channel. Especially in multihop situations a store and forward solution using the 802.11 backoff mechanism can only carry a very low traffic, due to the "hidden terminal" and "exposed terminal" problems. Our proposal is able to offer a solution, which results in a very efficient usage of the spectrum in single-hop and multi-hop scenarios. Future simulations will focus on reservation collisions and the problem of fair resource sharing. Dealing with legacy stations is another challenge. As legacy stations do not understand the reservation protocol, they severely interfere reserved TXOPs. This increases the delay and disturbs multihop communication. Further enhancements of the protocol will regard this aspect.

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