A cut-through switching technology for IEEE 802.11

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***Abstract*— The market for *Wireless Local Area Networks (WLANs)* based on *Institute of Electronics and Electrical Engineering (IEEE)* 802.11 has grown constantly in the recent years. Neither 802.11 itself nor one of its extensions regards multihop communication or forwarding mechanisms. As the actual market growth is substantially based on the *Small Office Home Office (SOHO)* and home user market, future 802.11 ad hoc networks should not only support *Quality of Service (QoS)* – as it will be provided by the upcoming IEEE 802.11e – but also multihop communication. In this paper, we survey a mechanism for relaying of data in 802.11 and give simulations results.**

***Index Terms*— IEEE 802.11e, Multihop, QoS, Wireless Switching**

I. INTRODUCTION

THE market for *Wireless Local Area Networks (WLANs)* has grown constantly in the recent years. WLANs have become affordable and useful for home networks. Multimedia applications like video streaming or *Voice over IP (VoIP)* rely on *Quality of Service (QoS)*. Therefore the *Institute of Electronics and Electrical Engineering (IEEE) Task Group E (TGe)* has proposed an ammendment to include prioritization mechanisms [1]. As 802.11a [2] and 802.11g [3] offer up to 54 Mb/s at 5 GHz respectively 2.4 GHz, high data rates combined with 802.11e support for multimedia applications are available. To replace the wired infrastructure by wireless links between multimedia components, a WLAN must offer ad hoc mechanisms supporting multihop connections. 802.11 does not offer any relaying functions besides the usage of the *Distribution Service (DS)* in an *Extended Service Set (ESS)* with help of two or more *Access Points (APs)*. Of course, the installation of multiple APs in a home environment is not desirable. Hence we survey a cut-through switching technology for 802.11 as proposed in [4]. Based on simulations in 2002 we give simulative results of this method.

This paper is outlined as follows. Following an introduction to 802.11 and 802.11e, we explain a cut through multihop concept for the 802.11 *Medium Access Control (MAC)*. Afterwards we give simulative results. In this paper, we consider single frequency multihop solutions for 802.11. All *Stations (STAs)* are grouped into the same *Basic Service Set (BSS)*, thus allowing them to communicate directly when in transmission range. As the *Physical Layer (PHY)* for our simulations we consider 802.11a.

II. IEEE 802.11

This section roughly explains the *Quality of Service (QoS)* supporting *Medium Access Control (MAC)* protocol 802.11e. As 802.11e is an extension to 802.11, it bases on the same concepts. Thus we only describe 802.11e. All the details of the 802.11e are beyond the scope of this paper. See [5] for a better overview.

A. The 802.11e MAC protocol

The basic 802.11e MAC protocol is the *Enhanced Distributed Channel Access (EDCA)* based on *Carrier Sense Multiple Access (CSMA)*. An *Independent Basic Service Set (IBSS)* typically has no central coordination instance and therefore uses the EDCA. *MAC Service Data Units (MSDUs)* of arbitrary lengths (up to 2304 B) are delivered after detecting that there is no other transmission in progress on the *Wireless Medium (WM)*. For each successful reception of a frame, the receiving *Station (STA)* immediately acknowledges the frame reception by sending an *Acknowledgment (ACK)* frame. The failure of such an ACK indicates a physical collision on the WM. *Collision Avoidance (CA)* reduces the probability of such collisions. As part of CA, before starting a transmission each *Access Category (AC)* performs a backoff procedure. It has to keep sensing the WM for an additional random time after detecting the WM as being idle for a minimum duration called *Arbitration IFS (AIFS)*, which is dependent on the AC.

To reduce the hidden STA problem inherent in CSMA networks, 802.11 also defines a *Request To Send/Clear To Send (RTS/CTS)* mechanism, which can be used optionally. Before transmitting data frames, a STA may transmit a short *Request To Send (RTS)* frame, followed by the *Clear To Send (CTS)* transmission by the receiving STA. The RTS and CTS frames include the information of how long it takes to transmit a subsequent data frame and the corresponding ACK response. Thus, other STAs close to the transmitting STA and hidden STAs close to the receiving STA will not start any transmissions. Between two consecutive frames in the sequence of RTS, CTS, data, and ACK frames, a *Short Interframe Space (SIFS)* gives transceivers the time to turn around. It is important to note that SIFS is shorter than any AIFS, which gives CTS and ACK frames always the highest priority for the channel access.

Furthermore 802.11e introduces the *Hybrid Coordinator (HC)*, which works as a centralized controller for all other STAs within the same *Quality of Service Basic Service Set (QBSS)*. Since the HC is the only STA in an infrastructure QBSS which does not have to perform a backoff, but can transmit at any time the WM has been idle for a duration equal to *Point (Coordination Function) Interframe Space (PIFS)*, it has highest priority of all STAs. It can therefore guarantee service level agreements as it has full control over the access of the WM. Unfortunately this absence of a 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. Multihop procedures for 802.11

As stated in section I ad hoc networks naturally demand uncomplicated connectivity. Hence no infrastructure should be needed. The high attenuation of walls at 5 GHz is another reason that leads to the needs of multihop communication. Even if in dense populated home environments one exclusive, unshared frequency is available, using two or more *Hybrid Coordinators (HCs)* in a single *Wireless Local Area Network (WLAN)* is problematic, as presented in section II-A. Thus we discuss a multihop solution using the *Enhanced Distributed Channel Access (EDCA)* only, as it is the *Coordination Function (CF)* which fits best the demands of an ad hoc WLAN.

To show the basic principles of a cut-through switching technology as proposed in [4] a triple hop line consisting of *Stations (STAs)* A, B and C is used, see Fig. 1.

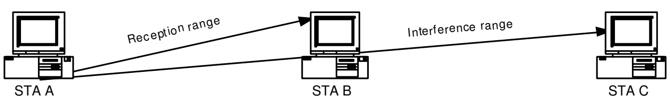

Fig. 1. STA A is in reception range of STA B, inside of interference but out of reception range of STA C.

STA B forms the intermediate node which forwards data from STA A to STA C. As the circles indicate STA A may be out of reception range of STA C but can still be in interference range to it. As the routing functionality is not part of the *Medium Access Control (MAC)*, we consider that a route between the source and the destination has already been established.

Fig. 3 presents an example. There are up to four address fields in a DATA frame. In 802.11 all address fields, *Destination Address (DA)*, *Source Address (SA)*, *Receiver Address (RA)* and *Transmitter Address (TA)*, are only used when a frame is transmitted via the *Distribution Service (DS)*. Fig 2 shows the address fields. To keep *Request To Send (RTS)* and

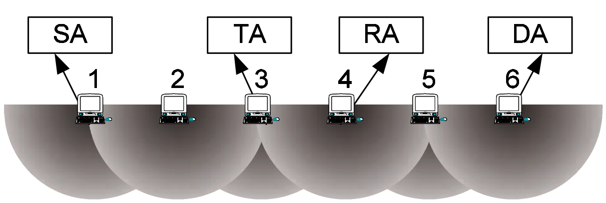

Fig. 2. Up to four address fields are used in 802.11. The address field TA and RA change with every hop. SA and DA are fixed during the transmission.

Clear To Send (CTS) frames as short as possible, they include only the necessary address fields. Thus methods for multihop connections as proposed in [6] and [7] cannot be easily integrated into 802.11 as these methods use modifications on the structure of the MAC frames. Therefore the proposal for multihop procedures in 802.11 surveyed here and in [4] focuses on backward compatibility and requires only minor changes to the MAC protocol.

A basic approach to include multihop procedures into 802.11 is a simple store and forward mechanism. Every frame which is to be forwarded, has to be put into the according queue belonging to the *Access Category (AC)* of the frame. Therefore every hop of a route adds an unpredictable delay to the transmission of a frame.

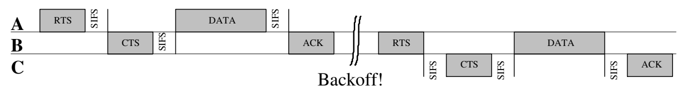

Fig. 3. After each successful reception a backoff has to be performed

To overcome the unpredictable additional delay included in every hop, leaving out the backoff in between every forwarding hop is proposed, see Fig. 4. Using only a *Short Interframe*

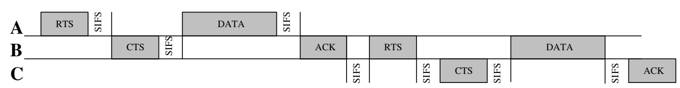

Fig. 4. After a SIFS interval the frame is immediately forwarded. Usage of RTS/CTS is optionally.

Space (SIFS) interval to relay the data to next the hop, gives the forwarding node highest priority on the *Wireless Medium (WM)*. In a centrally coordinated scenario, even a HC would not be able to interfere this forwarding transmissions. Therefore a HC would not be able to control the WM any longer as it is needed for time bounded services. In an *Independent Basic Service Set (IBSS)* a cut-through switching method is capable of increasing the traffic which can be carried.

IV. Evaluation

A. Methodology

We use event-driven stochastic simulations to discuss the efficency of the cut-through multihop procedure in 802.11. Simulation campaigns have been performed for the 802.11a *Physical Layer (PHY)* that allows up to 54 Mb/s in the 5 GHz license exempt band.

The simulations were performed using the *Wireless Access Radio Protocol 2 (WARP2)* simulation environment developed at the Chair of Communication Networks, Aachen University [8]. It is programmed in *Specification and Description Language (SDL)* using Telelogics TAU SDL Suite (previously named *SDL Design Tool (SDT)*). The error model used in WARP2 to accurately simulate the WM is presented in [9].

B. Results

The scenario simulated is shown in figure 5. Ten STAs are placed in a line. The distance between them is equal and varies from 5m up to 20m. The first and the last STA of this multihop lines are source and destination of the traffic to be carried by

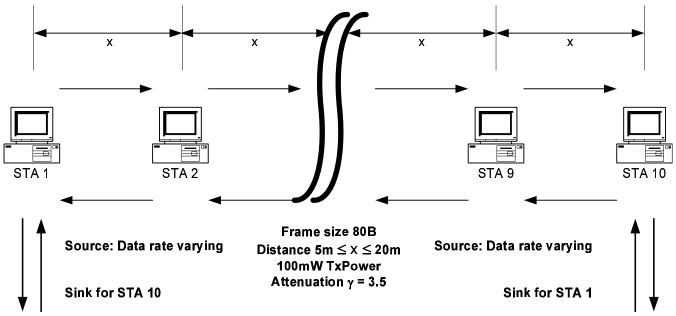

Fig. 5. The simulated scenario consists of a ten hop line. The first and last STA in this line are source and destination to each other. Intermediate nodes forward data only. They do not generate any traffic by themself.

the network. This can be seen as a full-duplex connection. The packet size is 80 B. As 802.11 performs best when using long frames, 80 B can be seen as worst case. An 80 B size frame is an assumption for *Voice over IP (VoIP)* traffic as presented in [10]. Our simulations present therefore a lower bound for the multihop case. For the one hop route the maximum throughput can be easily calculated. An upper bound regarding the throughput can be easily calculated. Assuming a STAs which transmits always at the earliest backoff interval equal to zero, frames of 80B size, at 6 Mb/s a maximum throughput of $\frac{80B*8Bit/B}{DIFS+176\mu s+DIFS+44\mu s} = 2.37Mb/s$ can be achieved, where $176\mu s$ is the duration to transmit 80B and $44\mu s$ is the duration of one *Acknowledgment (ACK)* frame at 6 Mb/s.

1) Performance evaluation of multihop connections prioritized by a SIFS instead of backoff: Fig. 6 presents the results on throughput when both traffic source STAs offered 64 kb/s. All PHY modes are able to carry the offered except for *Binary Phase Shift Key (BPSK)*1/2. At 20m distance it is no more capable to carry the offered traffic. Figures 7 through 10 show results of increased offered traffic. The offered load cannot be carried by all PHY modes at all distances. As the distances increase, the bit error rate increases also. On the other hand the interference power from neighboring STAs decreases as well. But this decrement does not balance out the increment of the bit error rate. Therefore less traffic can be carried. Although this multihop procedure is not immune to the neighborhood capture effect described in [11], [12], it is capable of carrying higher offered data rates than a store and forward procedure. Simulation results show, that the increment of the traffic offered at the source STAs decreases the carried traffic. As the source STAs have got only one neighbor they are more likely to find the WM as free, thus allowing them to transmit which severely interferes intermediate nodes. A retransmission is then needed. The BPSK PHY mode is too slow in this scenario since it suffers from frequent collisions but cannot retransmit the frames fast enough. Therefore it is not able to carry the offered traffic. This PHY mode has got a higher transmission range but suffers in this comparison from the equal number of hop for all PHY modes.

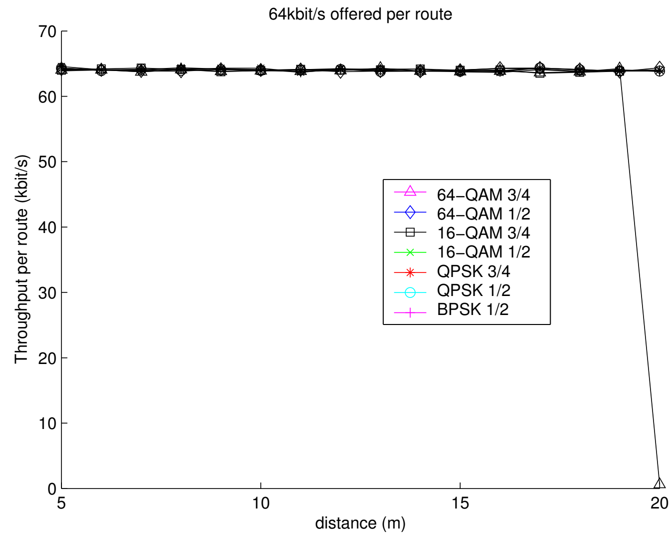

Fig. 6. 64 kb/s offered per route. The offered traffic can be carried.

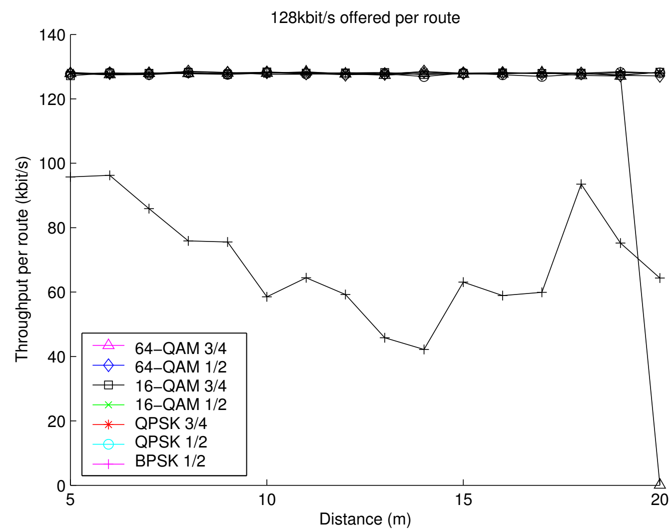

Fig. 7. At 128 kb/s offered traffic per route QAM 3/4 fails.

V. Conclusions

A store and forward solution using standard backoff of 802.11 decreases the throughput significantly as the probability of a successful transmission decreases as well. By a simple priorizing mechanism [4] the throughput of an ad hoc *Wireless Local Area Network (WLAN)* based on *Institute of Electronics and Electrical Engineering (IEEE)* 802.11 using multihop connections can be significantly increased. However, the distributed access to the *Wireless Medium (WM)* still limits the maximum throughput since *Stations (STAs)* interfere with each other as they are mutual hidden. The method described in [4] is therefore of very limited use in a multihop environment. As the 802.11 protocol has never been designed for multihop connections new methods are needed to support the upcoming Mesh networks.

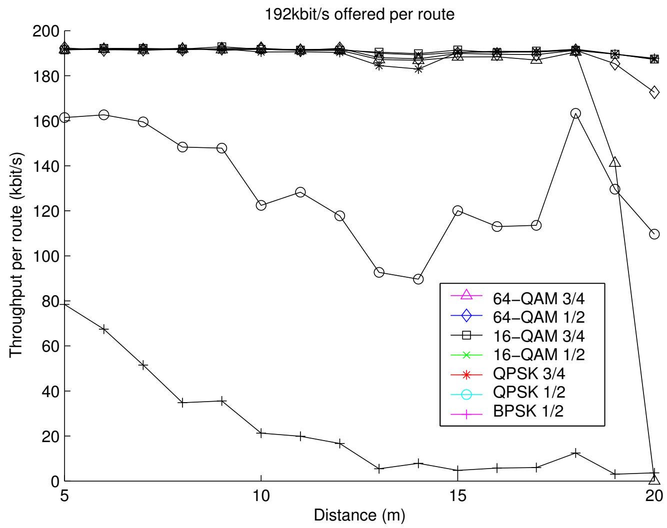

Fig. 8. 192 kb/s offered per route. BPSK 1/2 and QPSK 1/2 PHY mode cannot carry the offered traffic anymore.

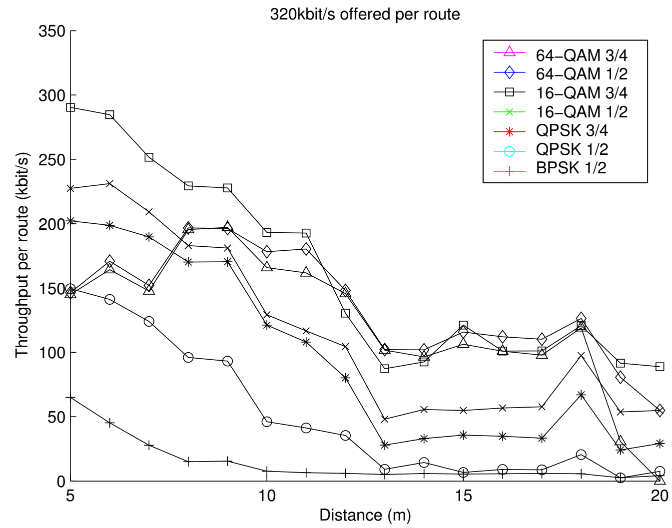

Fig. 10. 320 kb/s offered per route. No PHY mode can carry the offered traffic anymore.

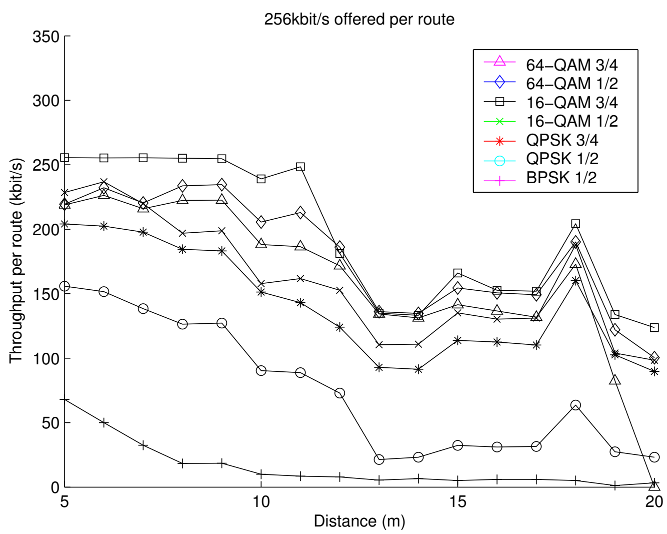

Fig. 9. 256 kb/s offered per route. Due to increased packet error ratios and constant collisions no PHY mode can carry the offered traffic at far distances.

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