IEEE 802.11 or ETSI BRAN HIPERLAN/2: Who will win the race for a high speed wireless LAN standard ?

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Abstract — **The demand for broadband communications is rapidly increasing as small to medium sized businesses and private users add Internet access and remote multimedia to their daily routines. Two major standardization bodies are currently working towards a standard for high speed wireless LANs: IEEE 802.11 and ETSI BRAN HIPERLAN/2.**

This paper gives a short overview of both standards including the PHY and MAC layer. The performance of both is compared under equal conditions, analytically and by simulations. Based on the outcome of the performance analysis the question whether IEEE 802.11 or HIPERLAN/2 will win the race will be discussed.

I. Introduction

IEEE 802.11 has finished the specification for wireless LANs with 1 and 2 Mbit/s in November 1997 [1] and is currently in the final stage of the extension to the standard for a 5 GHz PHY layer which will offer 6 to 54 Mbit/s on the air [2]. The MAC layer will be unchanged and not optimized to the higher data rates.

The *Broadband Radio Access Networks* (BRAN) project within ETSI will provide facilities for access to wired networks in both private and public context by the year 2000 [3]. The BRAN project will standardize only the radio access network and some of the interworking functions to different core networks [4]. The core network specific functions will be left to the corresponding fora (e. g. ATM Forum and *Internet Engineering Task Force*, IETF). Currently the main activity in BRAN is the specification of HIPERLAN/2 (*HIgh PERformance Local Area Networks – Type 2*). It is expected that stable drafts of the HIPERLAN/2 standard will be available by the end of this year.

As both standards aim at the same user society it is of major interest to investigate the performance of both in terms of throughput, delay and *Quality of Service* (QoS) support. In this paper the basic characteristics of both standards are explained and the performance is evaluated. Section II describes the physical layer which is common to both standards. Different from the PHY layer the MAC protocols differ significantly, which will be explained in Section III. The performance of both systems will first be derived analytically, while computer simulations gives an impression of the possibility to support QoS (Section IV). The conclusions will try to answer the question asked in the title.

II. Physical Layer

Both standardization bodies have worked together in order to harmonize the physical layer for 5 GHz [2, 5]. The PHY layer offers the transmitting and receiving service on the wireless medium. It uses *Orthogonal Frequency Division Multiplexing* (OFDM) with 48 active sub-carrier plus 4 sub-carrier for pilot symbols using an FFT size of 64. The operating frequency is between 5 and 6 GHz with a bandwidth of 20 MHz per frequency channel. The PHY layer offers different modulation schemes and coding rates as listed in Table 1. This results in different data rates on top of the PHY layer. The MAC protocol determines the PHY mode to be used.

Table 1: PHY modes of 802.11 and HIPERLAN/2

Modulation	**Code Rate Rate**	**Net rate on top of PHY**	**Byte per Symbol**
BPSK	1/2	6 Mbit/s	3
BPSK	3/4	9 Mbit/s	4.5
QPSK	1/2	12 Mbit/s	6
QPSK	3/4	18 Mbit/s	9
16-QAM	3/4	36 Mbit/s	18
HIPERLAN/2 only			
16-QAM	9/16	27 Mbit/s	13.5
IEEE 802.11 only			
16-QAM	1/2	24 Mbit/s	12
64-QAM	2/3	48 Mbit/s	24
optional			
64-QAM	3/4	54 Mbit/s	27

A. 802.11 OFDM Frame Format

The 802.11 *Physical Layer Convergence Procedure* (PLCP) maps a MAC PDU into a frame format designed for the OFDM radio transceiver.

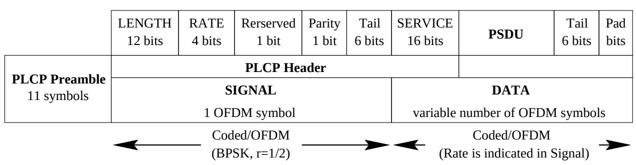

Figure 1: 802.11 OFDM frame format

The frame format of the OFDM PLCP is shown in Figure 1. It consists of the PLCP Preamble, the PLCP Header, the PSDU, the Tail and Pad bits.

The PLCP Preamble contains 9 repetitions of a "short training sequence" used for AGC convergence, antenna selection, timing and coarse frequency acquisition in the receiver and two repetitions of a "long training sequence" with a guard interval in front, which are used for channel estimation and fine frequency acquisition in the receiver.

The PLCP Header consists of a LENGTH field, a RATE field, reserved, parity and tail bits and a SERVICE field. All of these except the SERVICE field constitute a separate single OFDM symbol, denoted SIGNAL, which is transmitted with the most robust combination of modulation and coding rate. The SERVICE field of the PLCP Header and the PSDU with the tail and pad bits appended, denoted as DATA, are transmitted at the data rate described in the RATE field and may constitute of multiple OFDM symbols. The tail bits in the SIGNAL symbol allow to decode the RATE and the LENGTH fields immediately after their reception. The knowledge of RATE and LENGTH is required for decoding the DATA part of the packet. In addition, it also enables to augment the *Clear Channel Assignment* (CCA) mechanism by predicting the duration of the packet, even if the data rate is not supported by the station [2].

B. HIPERLAN/2 OFDM Frame Format

Different from the 802.11 OFDM frame format the HIPERLAN/2 OFDM frame format does not include protocol specific fields. The length and rate of the HIPERLAN/2 OFDM frame is determined on MAC layer level (see Section III.B). The PHY Preamble is shortened to 2-4 OFDM symbols [5]. This is possible due to the frame based MAC protocol.

III. MAC PROTOCOLS

The MAC protocols of 802.11 and HIPERLAN/2 differ significantly as 802.11 uses a distributed access scheme whereas HIPERLAN/2 is centrally organized. The following two Sections give a short overview of the MAC protocols, details can be found in [1, 6, 7, 8].

A. IEEE 802.11 MAC Protocol

The IEEE 802.11 MAC protocol provides two types of service: *asynchronous* and *contention free*. The asynchronous type of service is provided by the *Distributed Coordination Function* (DCF) which implements a *Carrier Sense Multiple Access/Collision Avoidance* (CSMA/CA) protocol as the basic access method. The contention free type of service is provided by the *Point Coordination Function* (PCF) which basically implements a polling access method. The PCF itself relies on the asynchronous service provided by the DCF [1, 7, 8, 9, 10].

As the DCF is based on CSMA/CA it uses *Inter-Frame Spaces* (IFS) to control the access to the medium. In order to determine whether the medium is free, a station has to use the carrier sense function for a specified IFS. 802.11 specifies four different IFS which represent three different priority levels for the channel access. The shorter the IFS the higher the priority. The IFS are specified as time gaps on the medium and are independent of the channel data rate.

Short IFS (SIFS): The SIFS is used for the immediate acknowledgement (ACK frame) of a data frame, the answer (*Clear to Send* (CTS) frame) to a *Ready to Send* (RTS) frame, a subsequent MPDU of a fragmented MSDU, response to any polling using the PCF, and any frames of the *Access Point* (AP) during the *Contention Free Period* (CFP).

Point Coordination Function IFS (PIFS) The PIFS is used by the AP operating under the PCF to gain access to the medium at the start of the CFP.

Distributed Coordination Function IFS (DIFS): The DIFS is used by stations operating under the DCF to gain access to the medium to transmit data or management frames.

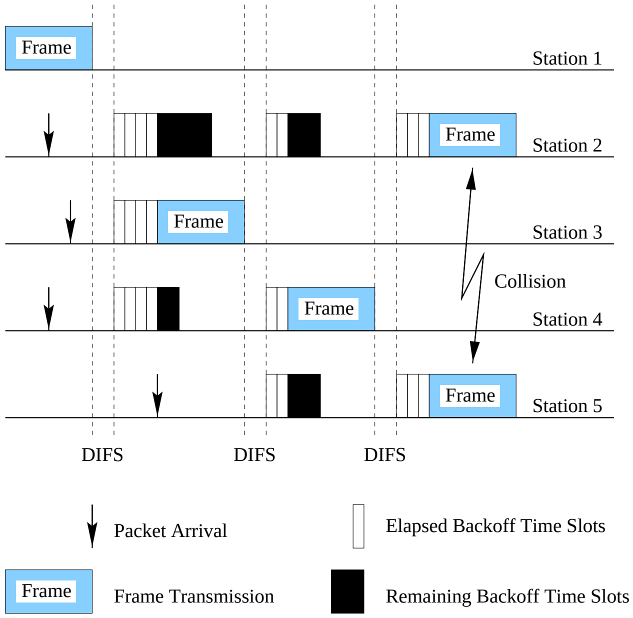

Figure 2: Basic access mechanism in 802.11

Distributed Coordination Function (DCF) According to the DCF (see Figure 2) a station must sense the medium before initiating the transmission of a packet. If the medium is sensed as being idle for a time interval greater than a DIFS then the station transmits the packet. Otherwise the transmission is deferred and the back-off process is started. The back-off scheme used in IEEE 802.11 is denoted as binary exponential back-off which means that the *Contention Window* (CW) is doubled if consecutive collisions occur. The back-off timer is decremented only when the medium is idle, whereas it is frozen when another station is transmitting. Each time the medium becomes idle, the station waits for a DIFS and then periodically decrements the back-off timer.

As soon as the back-off timer expires, the station is allowed to access the medium. If two or more stations start transmission simultaneously a collision occurs. Unlike wired networks (e.g. with CSMA/CD), in a wireless environment collision detection is not possible. Hence, a positive acknowledgement is used to notify the sending station that the transmitted frame has been successfully received. The transmission of the acknowledgement is initiated at a time interval equal to the SIFS after the end of the reception of the previous frame.

To deal with the hidden station problem the IEEE 802.11 MAC protocol includes a mechanism which is based on the exchange of two short control frames: a RTS frame which is sent by a potential transmitter to the receiver and a CTS frame which is sent by the receiver in response to the received RTS frame. Both frames include a duration field that specifies the time necessary to complete a frame transmission cycle. This information is used to update the *Net Allocation Vector* (NAV), a timer which — unlike the back-off timer — is continuously decremented irrespective of the status of the medium. All stations with the NAV set defer from accessing the medium.

Point Coordination Function (PCF) In order to support time-bounded services the IEEE 802.11 standard defines the PCF to permit a *Point Coordinator* (PC, usually the AP) to have priority access to the medium. Although the PCF is optional, all stations are able to obey the medium access rules of the PCF, because they are based on the DCF. Stations which are able to respond to polls by the PC are called *CF–Pollable*. Besides the AP, only these stations are able to transmit frames according to the PCF.

The PCF controls the frame transfers during the CFP which alternates with the *Contention Period* (PC) under the control of the DCF. The CFP is periodically repeated in time and starts with the transmission of a beacon. The beacon contains the maximum duration of the CFP (*CFPMaxDuration*) and all stations set their NAV to *CFPMaxDuration*.

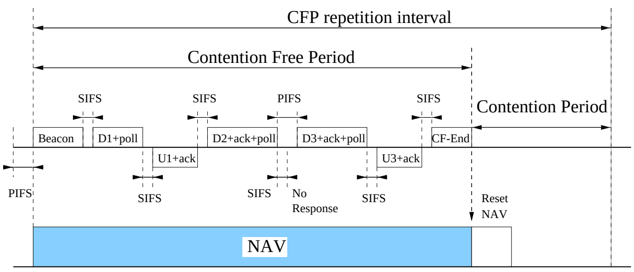

Figure 3: Example of PCF Frame Transfer

Figure 3 shows an example of a sequence of frame transmissions during a CFP. Usually the gap between two transmissions under the PCF is a SIFS unless a station does not respond to a *CF–Poll*. In the later case the PC regains control of the medium after a PIFS. With the transmission of a CF-End frame the PC can prematurely end the CFP. All stations reset their NAV in this case.

B. ETSI BRAN HIPERLAN/2 MAC Protocol

The MAC instances in the AP and the *Mobile Terminal* (MT) are responsible for controlling the access of the HIPERLAN/2 radio interface. In this centrally controlled approach the AP assigns the radio resources within the HIPERLAN/2 MAC frame [4]. This assignment of resources for the individual MTs and their connections is not static, but may change from MAC frame to MAC frame with a very high dynamic.

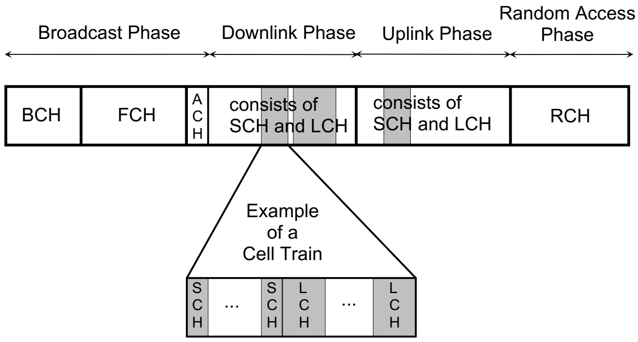

Figure 4: HIPERLAN/2 MAC Frame

The fixed length HIPERLAN/2 MAC frame ($t_{frame} = 2\ ms$) consists of four major phases as shown in Figure 4 [6]:

Broadcast Phase — broadcast
: The broadcast phase consists of *Broadcast Control Channel* (BCH), *Frame Control Channel* (FCH) and *Access Feedback Channel* (ACH).
The BCH is used by the AP to broadcast basic radio cell information such as the identifier of the AP and the transmit power level. Furthermore, it points to the FCH and RCH indicating where the respective channels are located within the MAC frame.
In the FCH the AP provides the list of contents for the dedicated downlink and uplink phases.
The ACH includes feedback on the RCH of the previous MAC frame. Successful receptions are acknowledged.

Downlink Phase — downlink direction
: The downlink phase consists of *Short Channels* (SCH) and *Long Channels* (LCH). In this downlink phase the actual user and control information dedicated to the respective MTs and their connections is transmitted. This information is organized in groups of variable length, so called cell trains. Each cell train carries the information assigned to one specific MT.

Uplink Phase — uplink direction
: The uplink phase uses basically the same structure as the downlink phase.

Random Access Phase — uplink direction
: The *Random Access Channel* (RCH) is used for the initial access to the network, for handover indication and for requesting radio resources (*Resource Requests*, RR). The collision resolution process is based on a binary exponential back-off comparable to the one used in IEEE 802.11. Therefore, each RCH has to be acknowledged in the next frame using the ACH.

A cell train groups two types of DLC PDUs (see Figure 4). *Long Channel* (LCH) PDUs carry mainly the payload of a connections. The size of this PDU is 54 Byte, whereby 48 Byte are allocated for the payload, the rest is used for DLC header. *Short Channel* (SCH) PDUs of 9 Byte carry DLC control information such as ARQ acknowledgements. Variable amounts of LCH and SCH PDUs are assigned to

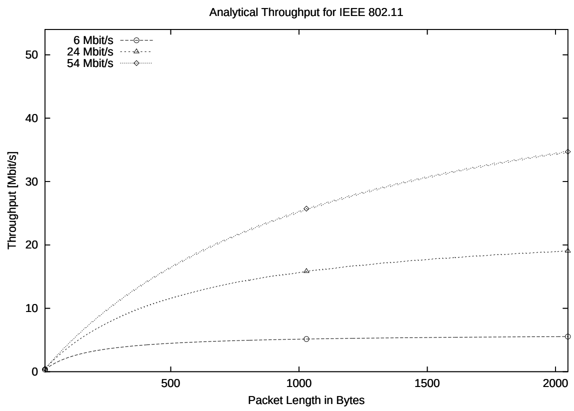

Figure 5: IEEE 802.11 Throughput for different Packet lengths

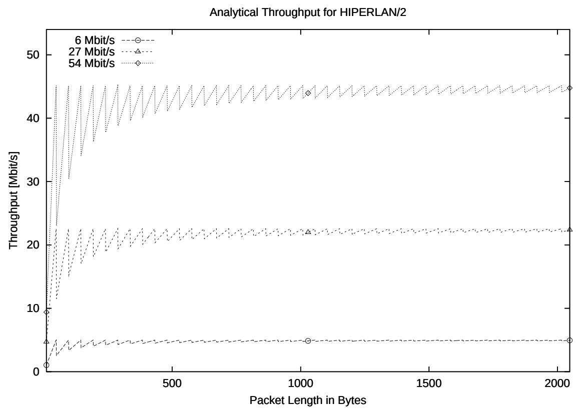

Figure 6: HIPERLAN/2 Throughput for different Packet lengths

the connections. Furthermore, SCH PDUs are used by the MT to request further resources for a particular connection in the next MAC frame. These *Resource Requests* (RR) may be transmitted either during the uplink phase in one of the dedicated SCH PDUs of a cell train or in the RCH in competition with other MTs [6, 11].

IV. PERFORMANCE EVALUATION

The performance depends on the network topology, the traffic mix, the QoS requirements and the protocol itself. Here, the focus is on the performance of the MAC protocols.

First the maximum throughput for different packet sizes and different combinations of modulation and coding rate is derived by analysis. In order to get a more complete figure of the performance and especially the QoS a scenario with a mixture of CBR and ABR traffic (or in other words: real-time isochronous and non-real-time asynchronous traffic) is investigated by computer simulations.

A. Analytical Approach

Throughput of IEEE 802.11 For a scenario of two wireless terminals the throughput of the DCF can be analytically calculated. It is assumed that only one terminal transmits packets and that its queue is never empty [12]. Therefore there are no collisions on the wireless medium, but it also is never idle for a period longer than required by the MAC protocol to allow the next access.

For this scenario, the transmission cycle for the basic access mechanism consists of the following phases, which are repeated over and over again:

1. DIFS
2. Back-off/Contention phase
3. Data packet transmission
4. SIFS
5. Acknowledgement packet transmission

As there are no collisions, the size of the back-off window CW is always $CW_{min} = 15$. Therefore the average back-off duration is

$$\frac{CW_{min}}{2} \cdot Slot\_Time \tag{1}$$

Table 2: Duration of the 802.11 Phases/Parameters

Phase/Parameter	**Duration [μs]**
Slot_Time	9
SIFS_Time	14
PIFS_Time	23
DIFS_Time	32
Preamble_Length	19.2
PLCP_Hdr_Length	4
Back-off/Contention	$7.5 \cdot 9 = 67.5$
Data Packet	$23.2 + 4 \cdot \left\lceil \frac{34+x}{BpS} \right\rceil$
Acknowledgement Packet	$23.2 + 4 \cdot \left\lceil \frac{14}{BpS} \right\rceil$

The transmission duration for a packet is calculated as $Preamble\_Length + PLCP\_Hdr\_Length + Data\ Packet$. Each data packet contains a MAC header of 34 byte. The duration of the phases can be seen in Table 2.

The total throughput is thus given by:

$$TP_{802.11} = \frac{\text{Packet length}}{\text{Transmission cycle duration}} \tag{2}$$

Figure 5 shows the throughput over the packet length. The throughput of IEEE 802.11 strongly depends on the packet length. The higher the data rate, the higher is the influence of the data packet length.

Throughput of HIPERLAN/2 The throughput for HIPERLAN/2 is calculated by first summing up the length of the channels and the overhead for uplink transmission as listed in Table 3 [11].

With a total number of 500 OFDM symbols per MAC frame, the total number of user PDUs (N_{PDU}) per MAC frame is given by:

$$N_{PDU} = \left(471 - \left\lceil \frac{9}{BpS} \right\rceil\right) \cdot \frac{BpS}{54} \tag{3}$$

The total throughput is thus calculated as

Table 3: Length of the HIPERLAN/2 control channels

Channel	Value [OFDM Symbols]
$BCH + Preamble_{BCH}$	$5 + 4 = 9$
FCH_{min}	6
ACH	3
$RCH + Preamble_{RCH}$	$3 + 4 = 7$
$UplinkOverhead$	$4 + \left\lceil \frac{9}{BpS} \right\rceil$

$$TP_{HIPERLAN/2} = N_{PDU} \cdot \frac{x}{\lceil \frac{x}{48} \rceil} \cdot \frac{8}{t_{frame}} \quad (4)$$

where x is the length of the user data packet in byte. In equation (4) the overhead introduced due to *Segmentation and Reassembly* (SAR) to packets of 48 byte in the *Convergence Layer* (CL) is already included [11].

Figure 6 shows the throughput over the packet length. The throughput of HIPERLAN/2 mainly depends on the SAR performance.

Comparison Table 4 shows a comparison of the throughput for long packets. It can be seen that the relative throughput for HIPERLAN/2 is independent from the PHY mode (82.7%–82.9%), whereas for 802.11 the relative throughput drops from 91.7% to 64.4%. The reason is that the MAC for 802.11 depends on carrier sensing which requires times (here IFS) which are independent from the PHY mode. Thus, the influence of the IFS is higher for high data rates.

Table 4: Throughput with 2048 byte long packets

PHY mode	802.11		HIPERLAN/2	
[Mbit/s]	[Mbit/s]	[%]	[Mbit/s]	[%]
6	5.5	91.7	5.0	82.7
24/27	19.1	79.6	22.4	82.9
54	34.8	64.4	44.8	82.9

In the analytical approach the influence of collisions is neglected. As IEEE 802.11 strongly suffers from collisions the real throughput is significantly lower than the one calculated in equation (2). As HIPERLAN/2 is mostly collision free, the real throughput is close to the values given in equation (4), if the additional overhead per MT is considered as shown in [11].

B. Simulation Results

In order to evaluate the QoS support a scenario has been created which consists of terminals with real–time isochronous traffic (*Constant Bit Rate*, CBR) and terminals with non–real–time asynchronous traffic (*Available Bit Rate*, ABR). The AP and one pollable terminal generate CBR traffic at 64 kbit/s each to evaluate the performance of transmitting a N–ISDN voice connection. The packet size for CBR is set to 48 byte. Four other, non–pollable terminals generate a variable background load. Their packet sizes are taken from an Ethernet trace-file [13], but the packets' inter arrival times are set to adjust the load generated by these terminals. The interval between the start of two PCF phases is set to 25 ms. The maximum duration of the PCF phase is 12.5 ms. PCF intervals of 5 ms and 50 ms have been investigated as well. The load is set to the generated ABR traffic divided by the PHY data rate which has been set to 24 Mbit/s (27 Mbit/s for HIPERLAN/2).

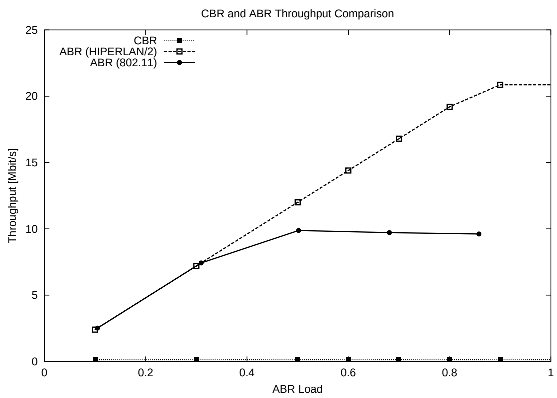

Figure 7: IEEE 802.11 and HIPERLAN/2 throughput in a CBR/ABR scenario

Figure 7 shows the throughput for CBR and ABR traffic. All CBR packets are transmitted for both MAC protocols and the average delays are nearly the same, but the throughput for ABR traffic differs significantly. With 802.11 only around 10 Mbit/s ($\sim 40\%$) can be served, whereas HIPERLAN/2 gives a maximum capacity of around 21 Mbit/s ($\sim 80\%$, as calculated in Section IV.A).

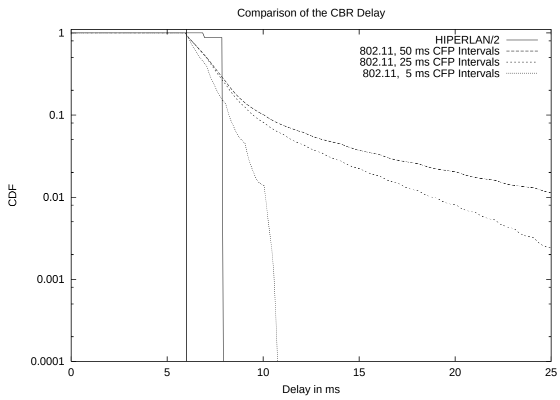

Figure 8: IEEE 802.11 and HIPERLAN/2 CBR delay distribution (100% load)

Figure 8 shows the complementary distribution function (CDF) of the total CBR delay including a packaging delay of 6 ms to fill up a 48 byte packet at 64 kbit/s. The packaging delay is the reason that all packets experience a delay of at least 6 ms. Although the average delays are nearly the same, the distribution shows some significant differences.

In IEEE 802.11 it is possible to transmit a packet immediately after arrival, therefore the delay curve decreases at 6 ms. The steepness of the curve strongly depends on the CFP interval. With a CFP interval of 5 ms the delay is limited to 11 ms (6 ms packaging + 5 ms MAC). Accordingly the delay with CFP interval 25 ms is bounded to 31 ms and with 50 ms to 56 ms. It has to be noted that a CFP interval of 5 ms is not very realistic, because the total throughput decreases dramatically with such a short CFP interval.

In HIPERLAN/2 the CBR delay is limited to 1 MAC Frame if a polling algorithm is implemented. This sums up to a total delay of 8 ms (6 ms packaging + 2 ms MAC) while offering a high ABR throughput. It has to be noted that this delay is deterministic.

Both simulations have been performed without errors on the channel. It is questionable whether repetitions of CBR packets in a voice connection are feasible.

V. Conclusions

Products according to IEEE 802.11 and HIPERLAN/2 are competing for the same customers, business users in the first place. In order to judge the market penetration of these products several issues have to be considered such as price, availability, usability and performance.

The price strongly depends on the complexity of the standards and the number of devices (economy of scales). As the PHY layer is mainly the same for 802.11 and HIPERLAN/2 the difference is given by the MAC protocols. The CSMA/CA protocol of 802.11 is much simpler in terms of processing power than the centralized MAC of HIPERLAN/2. Furthermore, BRAN specifies a complex ARQ and a *Radio Link Control Protocol* which adds to the complexity. Thus HIPERLAN/2 products have to come up with a powerful processor and/or some intelligent hardware.

IEEE 802.11 at 2.4 GHz with 1&2 Mbit/s (5&8 Mbit/s in proprietary solutions) is well introduced on a world-wide basis. 802.11 has proven to work and it is well-known. It will be hard for HIPERLAN/2 products to make up for 802.11. A major problem for 802.11 at 5 GHz is that the frequency band is only available in the U. S. In Europe this band is exclusively allocated to HIPERLANs. HIPERLAN/2 on the other hand is allowed to operate in the U.S. IEEE puts a strong effort on opening the European HIPERLAN band for 802.11. The outcome of it is open.

In terms of usability it is not expected to have significant differences between both standards. An advantage of 802.11 is its ad-hoc capability which means that stations can communicate without any AP, which is not possible with the HIPERLAN/2 basic specifications (BRAN works on an extension to support ad-hoc networking).

As shown in Section IV HIPERLAN/2 offers a much better performance compared to 802.11 especially at high data rates. Furthermore, the QoS support of 802.11 is very limited, whereas HIPERLAN/2 will be the first system in place to service high quality applications in a wireless LAN environment.

Summarizing there will be a trade-off between performance and price. Despite the availability of frequencies it can be imagined that 802.11 will be the dominating standard for low quality applications, whereas HIPERLAN/2 will dominate the market for high end users. Time will tell whether there is space for two different wireless LAN standards.

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