Performance Evaluation of the MAC protocol of the ETSI BRAN HIPERLAN/2 standard

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I. Introduction

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. The *Broadband Radio Access Networks* (BRAN) will provide facilities for access to wired networks in both private and public context by the year 2000 [1]. The BRAN project will standardize only the radio access network and some of the interworking functions to different core networks [2]. The core network specific functions will be left to the corresponding fora (e. g. ATM Forum and *Internet Engineering Task Force*, IETF).

ETSI BRAN HIPERLAN/2 consists of three layers, the *Convergence Layer* (CL) which adapts the *Higher Layer* protocols to the *Data Link Control* DLC layer and lies between *Network* and DLC layer, the DLC layer itself, and the PHY layer [2].

The main task of the CL is the *Segmentation and Reassembly* (SAR) of data packets which exceed the length of one DLC SDU (48 Byte). In case of ATM no SAR is necessary.

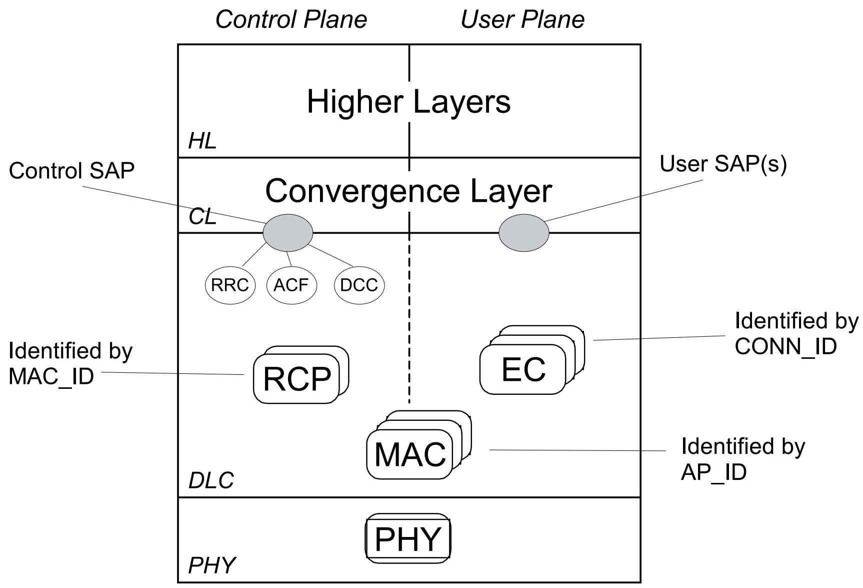

Figure 1: HIPERLAN/2 protocol stack

The HIPERLAN/2 (DLC) layer is composed of three major functional entities as depicted in Figure 1. The *Radio link Control Protocol* (RCP) defines all the DLC control information which is transmitted via the radio interface. Since HIPERLAN/2-DLC is core-network independent, RCP supports the services requested by the higher layer control functions and adapted by the convergence layer for terminal and connection handling as well as wireless specific functions. The *Error Control* (EC) entities of the DLC are responsible for secured transmission of user data, for RCP control messages no EC is used. The detection and recovery of transmission errors will be based on *Automatic Repeat reQuest* ARQ techniques. The *Medium Access Control* (MAC) scheme applies a centralized controlled concept, where the *Access Point* AP determines the structure of the MAC frame. In HIPERLAN/2 a load adaptive TDMA/TDD scheme is defined. For each individual MAC frame the AP assigns a specific amount of capacity for the *Mobile Terminal's* (MT) connections. The performance of the MAC protocol currently under standardization is the main focus of this paper.

The PHY layer offers the transmitting and receiving service on the wireless medium. It is harmonized with the evolving IEEE 802.11 PHY for 5 GHz [3]. It uses *Orthogonal Frequency Division Multiplexing* (OFDM) with 48 active sub-carrier out of 64 carriers. 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 DLC determines the PHY mode to be used.

Table 1: PHY modes of ETSI BRAN HIPERLAN/2

Modulation	**Code Rate**	**Gross rate on the air**	**Net rate on top of PHY**	**Byte per Symbol (BpS)**
BPSK	1/2	12 Mbit/s	6 Mbit/s	3
BPSK	3/4	12 Mbit/s	9 Mbit/s	4.5
QPSK	1/2	24 Mbit/s	12 Mbit/s	6
QPSK	3/4	24 Mbit/s	18 Mbit/s	9
16-QAM	9/16	48 Mbit/s	27 Mbit/s	13.5
16-QAM	3/4	48 Mbit/s	36 Mbit/s	18
		optional		
64-QAM	3/4	72 Mbit/s	54 Mbit/s	27

II. ETSI BRAN HIPERLAN/2 MAC PROTOCOL

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

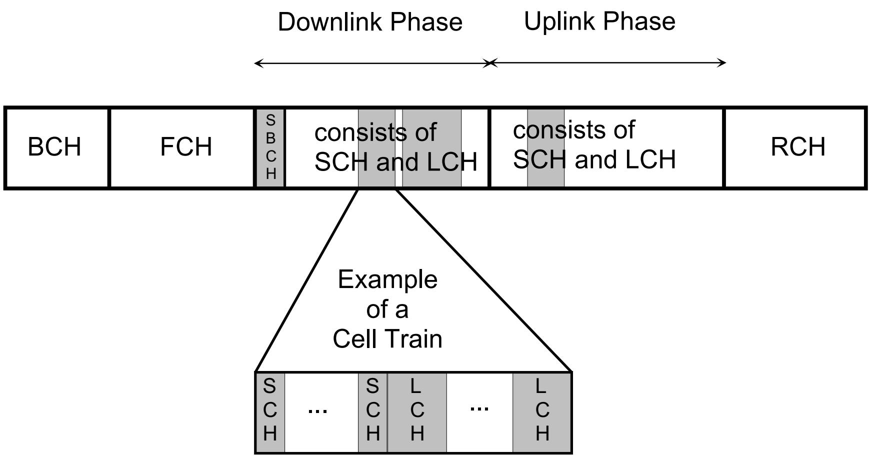

Figure 2: MAC Frame

The fixed length HIPERLAN/2 MAC frame ($t_{frame} = 1636\mu s$) consists of five major phases as shown in Figure 2 [4]:

Broadcast Channel (BCH) - downlink direction [5]
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 in the MAC frame.

Frame Control Channel (FCH) - downlink direction [6]
In the FCH the AP provides the list of contents for the dedicated downlink and uplink phases. Furthermore, it may include some acknowledgements for the RCH of the previous frame or other purposes.

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 Channels (RCH) - uplink direction
The RCH is used for the initial access to the network, for handover indication and for requesting radio resources (*Resource Requests*, RR).

A cell train groups two types of DLC PDUs (see Figure 2). *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 size carry DLC control information such as ARQ acknowledgements. Variable amounts of LCH and SCH PDUs are assigned to the connections in one cell train. 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.

Since the FCH serves as the directory for the uplink and downlink phases, its list of contents reflects the cell train structure. The FCH PDU carries a list of *Resource Grant Information Elements* (RG-IE) each defining a cell train of one MT, either uplink or downlink.

The RG-IE is organized in blocks of eight Byte. The block consists of the IE addressing the particular MT by its MAC identifier and determining the location of the cell train within the MAC frame by the start pointer field. The PHY mode of all SCH PDUs of that cell train is specified. The number of SCH and LCH PDUs allocated for this connection is set next. The PHY mode of the LCH PDUs can be specified on a per connection basis.

Besides dedicated cell trains the FCH announces also additional channels for global purposes. As an example the *Slow Broadcast Channel* (SBCH) is shown in the downlink phase of Figure 2. The SBCH broadcasts additional radio cell information which are not transmitted in the BCH. For the SBCH multiple MAC PDUs of SCH size may be allocated.

In this way the FCH carries a variable length PDU which is determined by the number of cell trains indicated, i. e. by the number of RG-IE, and the number of connections incorporated within a cell train. In order to allow early decoding of the relevant information contained in the FCH by the receiver, the FCH PDU is segmented in groups of constant length each protected individually by a *Cyclic Redundancy Check* (CRC). A group size of 27 Byte including 3 Byte CRC is currently proposed for the standard [7].

III. Analytical Approach

The HIPERLAN/2 MAC provides a huge flexibility to accommodate a large variety of MTs and connections on the one hand and different *Quality of Service* (QoS) requirements on the other hand. The actual data rate supported by the MAC can be adjusted for each MT individually by defining the allocated number of PDUs and their PHY mode.

However, in order to support such a dynamic structure the MAC introduces protocol overhead which requires resources of the radio interface. The dynamic nature of the MAC control channels presented in Section II limits mainly the available resources for user connections. In the following the available resources on top of the MAC are calculated under the assumption that a specific number of MTs (n_{MT}) and connections (n_{conn}) are active in a particular radio cell.

When calculating the MAC protocol overhead, the static and dynamic lengths of the control channels and the PHY modes assigned have to be considered. The length of the MAC frame phases in number of OFDM symbols is given by:

BCH: The BCH has a fixed length of 12 Byte and uses the PHY mode BPSK 1/2. The BCH follows the MAC frame preamble. The length of the BCH is given by

$$L_{BCH} = \frac{12}{3} + Preamble_{BCH} = 4 + Preamble_{BCH}. \tag{1}$$

FCH: The FCH is variable in length and build out of 27 Byte block consisting of 24 Byte for RG-IE and 3 Byte CRC-24. The total length is given by an RG for the SBCH (in this example) and one RG for each active connection (n_{conn}). The total length of the FCH equals

$$L_{FCH} = \left\lceil \left\lceil \frac{n_{conn} \cdot 8}{24} \right\rceil \cdot \frac{27}{BpS_{FCH}} \right\rceil, \tag{2}$$

where BpS_{FCH} is the number of Byte per Symbol determined by the chosen PHY mode (see Table 1).

RCH: The size of the RCH is determined by the number of RCH slots ($Slots_{RCH}$). Each RCH slot has the length of a SCH with BPSK 1/2 (equals 3 OFDM symbols) plus the PHY Preamble. The total length of the RCH is given by

$$L_{RCH} = Slots_{RCH} \cdot (3 + Preamble_{UL}). \tag{3}$$

SBCH: The SBCH in this example has a fixed length of 9 Byte (in our example) and uses the PHY mode BPSK 1/2. The length of the SBCH is given by

$$L_{SBCH} = \frac{9}{3} = 3. \tag{4}$$

Downlink and Uplink Phase: Basically, the downlink phase consists of LCHs only, if ARQ protocols are neglected. Thus, except a preamble heading the downlink phase, no additional overhead is introduced by the downlink. For the uplink one SCH per active connection is included in order to allow piggybacked resource requesting. Furthermore, each cell train is preceded by a PHY preamble. The total amount of uplink overhead is

$$L_{UL} = n_{MT} \cdot \left\lceil Preamble_{UL} + n_{conn} \cdot \frac{9}{BpS_{SCH}} \right\rceil. \tag{5}$$

With equations (1)-(5) the number of free OFDM symbols per MAC frame can be calculated. With a length of one OFDM symbol of $4\mu s$ and a MAC frame length of $t_{frame} = 2ms$ 500 OFDM symbols fit into one MAC frame. Setting the number of RCH slots to 3 ($Slots_{RCH} = 3$) and the length of the PHY preamble to 4 ($Preamble_{BCH} = Preamble_{BCH} = 4$) the number of free OFDM symbols for LCHs is given by:

$$\begin{aligned} L_{LCH} &= 500 - L_{BCH} - L_{FCH} - L_{RCH} - L_{SBCH} - L_{UL} \\ &= 468 - \left\lceil \left\lceil \frac{n_{conn} \cdot 8}{24} \right\rceil \cdot \frac{27}{BpS_{FCH}} \right\rceil - n_{MT} \cdot \left\lceil 4 + n_{conn} \cdot \frac{9}{BpS_{SCH}} \right\rceil \end{aligned} \tag{6}$$

The user data rate on top of the MAC layer is now calculated by dividing the free symbols by the number of symbols per LCH PDU ($\frac{54}{BpS_{LCH}}$) and calculating the number of 48 Byte payload fields per MAC frame:

$$Throughput = \left\lfloor \frac{L_{LCH} \cdot BpS_{LCH}}{54} \right\rfloor \cdot \frac{48 \cdot 8}{t_{frame}} \tag{7}$$

The throughput has been evaluated for two different scenarios and three different PHY modes. One scenario is given by considering one connection per MT and varying the number of active MT ($n_{conn} = 1$ & $n_{MT} = x$, Figure 3), the other scenario is defined by one active MT having a number of active connections ($n_{MT} = 1$ & $n_{conn} = x$, Figure 4). The PHY mode for the FCH and SCH are always the same for simplicity reasons. Table 2 summarizes the evaluation scenarios and parameters belonging to the plots in Figure 3 and 4.

Table 2: Evaluation scenarios and parameters

Scenario	**PHY mode FCH & SCH**	**PHY mode LCH**	**Plot**
$n_{conn} = 1$ $n_{MT} = x$	BPSK 1/2 $BpS_{FCH} = BpS_{SCH} = 3$	BPSK 1/2 $BpS_{LCH} = 3$	Figure 3 Box
$n_{conn} = 1$ $n_{MT} = x$	BPSK 1/2 $BpS_{FCH} = BpS_{SCH} = 3$	16-QAM 3/4 $BpS_{LCH} = 18$	Figure 3 Cross
$n_{conn} = 1$ $n_{MT} = x$	16-QAM 3/4 $BpS_{FCH} = BpS_{SCH} = 18$	16-QAM 3/4 $BpS_{LCH} = 18$	Figure 3 Circle
$n_{MT} = 1$ $n_{conn} = x$	BPSK 1/2 $BpS_{FCH} = BpS_{SCH} = 3$	BPSK 1/2 $BpS_{LCH} = 3$	Figure 4 Box
$n_{MT} = 1$ $n_{conn} = x$	BPSK 1/2 $BpS_{FCH} = BpS_{SCH} = 3$	16-QAM 3/4 $BpS_{LCH} = 18$	Figure 4 Cross
$n_{MT} = 1$ $n_{conn} = x$	16-QAM 3/4 $BpS_{FCH} = BpS_{SCH} = 18$	16-QAM 3/4 $BpS_{LCH} = 18$	Figure 4 Circle

As shown in Figure 3 the throughput strongly depends on the PHY mode of the LCH and the number of active MTs (which is obvious). The most interesting point is the influence of the PHY mode of the FCH and SCH. Using the same PHY mode for FCH, SCH and LCH the throughput decrease with the number of MTs by about 200 kbit/s per active MT for 16-QAM 3/4 and by about 100 kbit/s per active MT for BPSK 1/2. These numbers are significant, but tolerable. Using 16 QAM 3/4 for LCH and BPSK 1/2 for FCH and SCH the drop in throughput is increased to about 600 kbit/s per active MT which is three times higher than for using 16 QAM 3/4 for FCH and SCH as well.

Figure 4 shows similar results for varying the number of active connections per MT. But, the loss in capacity is only half that high compared to Figure 3. The reason for this is twofold. The FCH grows only by 4 Byte per connection instead of 8 Byte per MT and no PHY preamble has to be added for an additional connection of an already active MT.

Taking the results into account the design of a scheduler shall lead to a low number of active MTs per MAC frame. From the point of system throughput it is preferable to transmit long cell trains. This, however, will result in a very bursty transmission scheme. The influence of such a scheduling scheme on the transmission delays will be presented in the full paper.

IV. Conclusions

The full paper will give a more detailed performance evaluation of the HIPERLAN/2 MAC protocol with different core network configurations by means of computer simulations.

V. References

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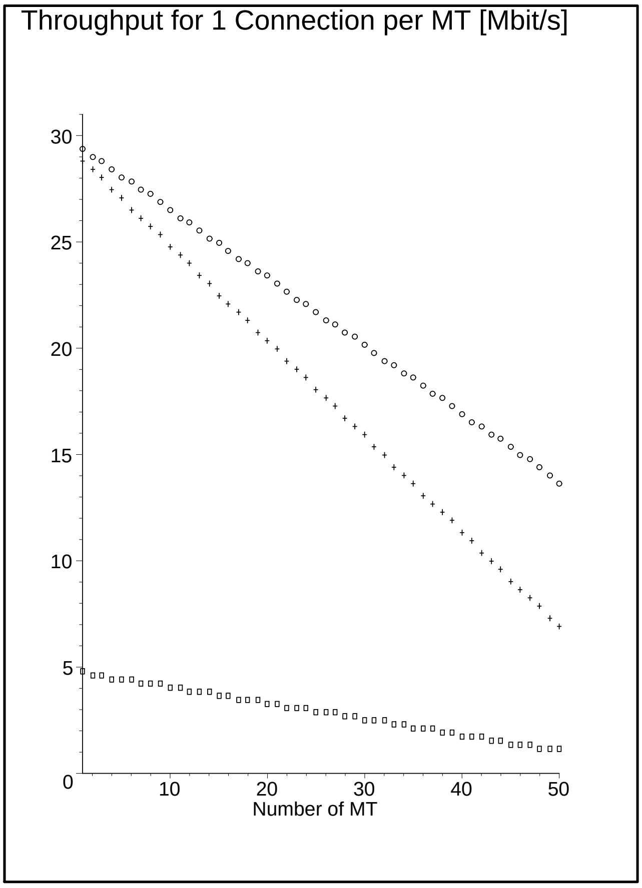

Figure 3: Throughput for different PHY modes over the number of MTs, see Table 2

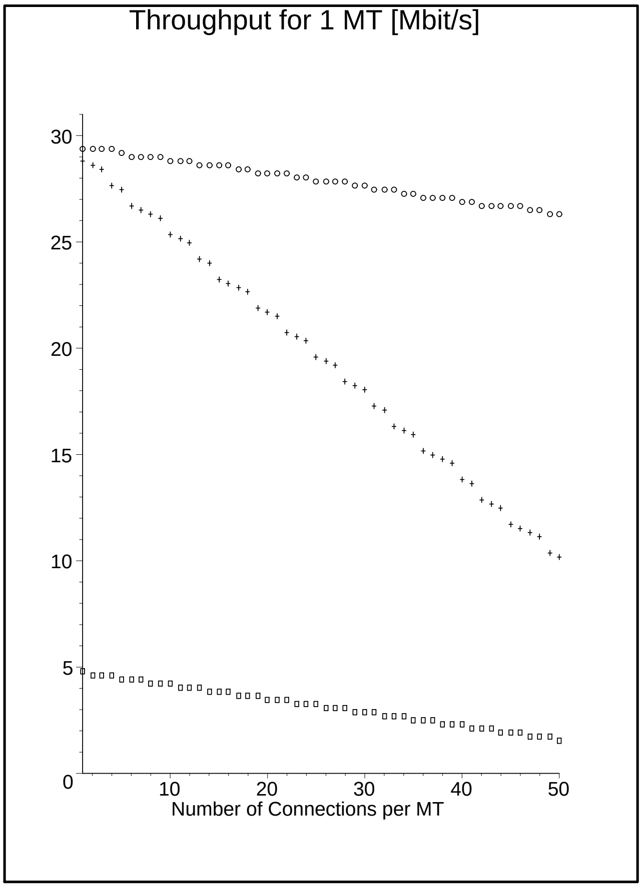

Figure 4: Throughput for different PHY modes over the number of connections, see Table 2

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