The HIPERMAN Standard – a Performance Analysis

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***Abstract*— Fixed broadband wireless access systems (FBWA) are becoming a challenging competitor to conventional wired last mile access systems like DSL and cablemodems. The ARC Group forecasts that FBWA connections will reach almost 28 millions by 2005 for both households and business. This will result in a portion of 24% in North America and 27% in Europe [1]. The IST project STRIKE is currently working on a demonstrator to show the benefit of advanced technologies that are added to the HIPERMAN standard. This paper gives an overview of the new ETSI/BRAN High PERformance Metropolitan Area Network (HIPERMAN) network. The Medium Access Control (MAC) and the physical layer (PHY) are described in detail. Especially the MAC protocol data unit (PDU) configuration is analyzed. Afterwards a performance evaluation based on several MAC configuration examples is provided.**

I. Introduction

This paper presents the HIPERMAN standard. Since the entire HIPERMAN standard is in ballot but scheduled to be published on 01/26/03, the paper is based on the latest draft 5 [2]. The HIPERMAN standard took the IEEE 802.16 [3] and the amendment of the IEEE 802.16a PHY (systems below 11GHz) as a baseline. Thus, both OFDM-based PHY layers shall comply with each other and a global OFDM system could emerge.

In the scope of the IST project STRIKE two main issues have been detected to enhance the system to fullfill the future requirements and let HIPERMAN become a success. Interworking with wireless LANs is being examined. Wide coverage of MANs and high data rates of WLANS as well as end-to-end Quality of Service (QoS) guarantees including both systems can be provided by using interworking mechanisms in MAN-LAN networks. By leveraging advanced antenna systems like beamforming, space-time coding or BLAST techniques, the system performance can be significantly increased.

In section II the HIPERMAN standard is described in details. Based on the introduced MAC PDU configurations a performance evaluation of the MAC protocol with an underlying OFDM PHY is presented in section III.

II. ETSI/BRAN HIPERMAN

HIPERMAN is an interoperable FBWA system operating at radio frequencies between 2 and 11 GHz. The scope of

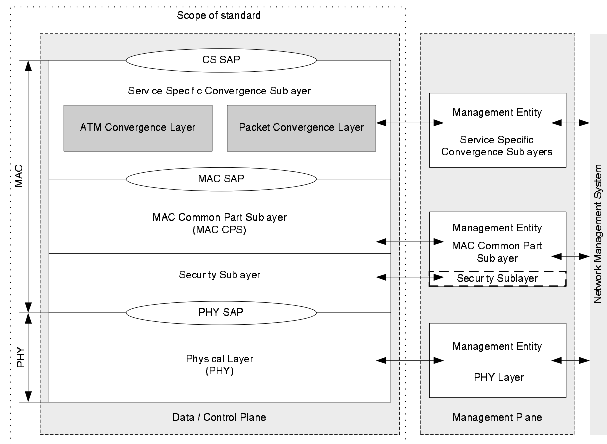

Fig. 1. HIPERMAN protocol layering

the HIPERMAN standard comprises the MAC and the PHY layer as illustrated in Fig. 1. It has been designed to fulfill today's most promising challenges: **Nonprofessional installation of terminals** to significantly cut the deployment cost, is enabled due to non line of sight (NLOS) operation capability. **Rapidly scalable infrastructure deployment** will decrease time to market for new broadband services which will be crucial for the success of new operators. **Efficient spectrum usage** enables operators to offer services requiring high peak bit rates. **Modular cost-effective growth** is possible because the main cost of radio access lies in the equipment itself. Radio offers the possibility of selective access, easier bridging of distances to customers than fiber or copper. **QoS support** for packet-based services is provided by the system.

A. Medium Access Control (MAC)

The MAC includes service specific convergence sublayers that interface higher layers. The MAC common part sublayer carries the key functions and below resides the privacy layer.

1) Service Specific Convergence Sublayer (CS): The Service Specific CS provides any transformation or mapping of external network data, received through the CS service access point (SAP). This includes classifying external network service data units (SDU) and associating them to the proper service flow identified by the connection identifier (CID). A

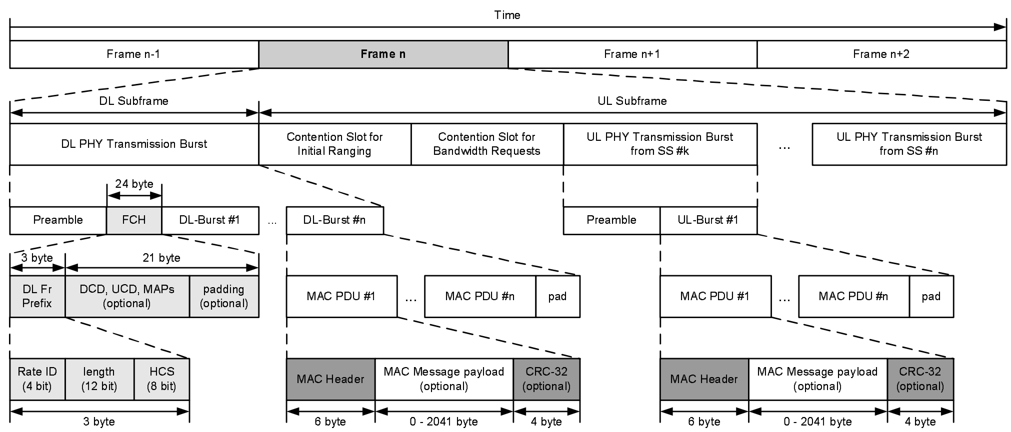

Fig. 2. Frame structure TDD

service flow is a unidirectional flow of packets that is provided with a particular QoS. The base station (BS) and subscriber station (SS) provide this QoS according to the QoS parameter set defined for the particular service flow. Payload header suppression (PHS) of the ATM or TCP/IP header is included. Multiple CS specifications enable interfacing with various protocols, e.g. ATM, IP, Ethernet.

2) MAC Common Part Sublayer (MAC CPS): MAC CPS provides system access, bandwidth allocation, connection establishment, and connection maintenance. It receives data from the various CSs classified to particular CIDs. QoS is applied to the transmission and scheduling of data over the PHY layer.

HIPERMAN is optimized for point to multipoint (PMP) configurations but may allow for flexible mesh deployments. In a mesh network, all mesh BSs and mesh SSs have to coordinate their transmissions. With distributed scheduling all the nodes coordinate their transmission in their two-hop neighborhood. The schedules (available resources, requests and grants) are broadcast, or established by direct requests and grants between two nodes. With centralized scheduling, the mesh BS gathers resource requests from all mesh SSs within a certain hop range. The actual schedule is not given in the grant message, but has to be computed by each node. This paper will focus on the PMP mode, where a central BS is coordinating transmission in both UL and DL direction.

HIPERMAN supports a frame-based transmission, in which the frame can adopt variable lengths. The frame structure for the OFDM PHY in time division duplex (TDD) mode is illustrated in Fig. 2. The frame consists of a DL-subframe and an UL-subframe, with the DL-subframe always preceding the UL-subframe.

A DL-subframe consists of only one DL PHY transmission burst starting with a preamble used for synchronization. The following frame control header (FCH, mandatory QPSK 1/2) contains the DL frame prefix to specify the modulation/coding (PHY mode) and length of the first DL-burst#1. The FCH or the DL-burst#1 contains the broadcast MAC control messages, i.e. DL and UL channel descriptor (DCD, UCD) and the UL- and DL-MAP. DCD and UCD define the characteristics of the pysical channel. The DL-MAP defines the access to the DL information and the UL-MAP allocates access to the UL channel. The burst profiles, e.g. PHY mode, in UL and DL direction are also specified by the DL- and UL-MAP. The FCH is followed by one or multiple DL-bursts, each transmitted with a different burst profile. Thus the whole MAC frame is specified by the FCH and the DL-burst#1.

UL-subframes consist of contention intervals scheduled for initial ranging (RNG-REQ) and bandwidth request (BW-REQ) purposes and one or multiple UL PHY transmission bursts, each transmitted from a different SS. Each UL PHY transmission burst consists of only one UL-burst starting with a preamble.

DL- and UL-bursts are carrying MAC PDUs. To form an integer number of OFDM symbols, a burst is filled up with padding bit. In DL direction PDUs with the same burst profile are combined to a DL-burst. The UL-burst only consists of PDUs comming from a single SS.

In TDD mode the transmitter/receiver transition gap (TTG) is inserted between DL- and UL-subframe and the receiver/transmitter transition gap (RTG) at the end of each frame to allow the BS and SSs to turn around. After the TTG, the BS receiver shall look for the first symbol of a UL-burst. After the RTG, the SS receivers shall look for the first symbols of QPSK modulated data in the DL-burst.

MAC PDUs consist of a fixed-length MAC header, a variable-length payload and an optional 32 bit cyclic redundancy check (CRC). Since the size of the payload is variable, the length of the MAC PDUs may vary between 6 and 2051 byte. This allows the MAC to tunnel various higher layer traffic types without knowledge of the formats of those messages. Two MAC header formats are defined: **Generic MAC Header** begins each MAC PDU containing either MAC management messages or CS data as payload. It contains all necessary information about the payload.

Each bandwidth request PDU solely consists of the **Band-**

width Request Header without any additional payload. The bandwidth request header is used to request additional bandwidth. The maximum request size for UL bandwidth amounts to 65535 byte.

CS data can be encapsulated into the MAC PDU payload either directly, i.e. a single complete MAC SDU becomes the payload, or packing and/or fragmenting of the SDUs may be optionally enabled. MAC management messages are carried as payload of the MAC PDUs as well.

Fragmentation is the process of dividing a MAC SDU onto one or more MAC PDUs with the aim to allow efficient use of the available bandwidth relative to the QoS requirements of a connection's service flow. The authority to fragment traffic on a connection is defined on its creation by the MAC SAP. The maximum size of a fragment may be negotiated during or after connection establishment. A fragmentation subheader is added in front of the fragmented SDU in order to be able to reassemble the fragments to the complete SDU upon reception.

Packing is the process of packing multiple MAC SDUs into a single MAC PDU. If packing is enabled for a connection the transmitting side has full discretion whether or not to pack. For connections with disabled automatic repeat request (ARQ) there are two packing modes: packing fixed-length MAC SDUs, or packing variable-length MAC SDUs. For the fixed-length mode no subheader are added and the information about the packed SDUs is implicitly contained in the generic MAC header. For ARQ enabled connections only the variable-length packing mode is available, where each packed SDU is preceded by a packing subheader.

Additional subheader for bandwidth requests, mesh or ARQ functionality are always put in front of the payload mentioned above. Thus if present, the MAC PDU payload consists of zero or more subheaders and zero or more MAC SDUs or fragments thereof.

The HIPERMAN ARQ mechanism is an optional part of the MAC layer and can be enabled on a per-connection basis during connection establishment. It is a bitmap-based ARQ mechanism based on the fragment sequence number of the fragmentation or packing subheader. The mechanism can either work as a cumulative, a selective acknowledge or a combined ARQ mechanism. The receiver uses ARQ feedback messages either piggybacked within a packed MAC PDU or as a payload of a standalone MAC PDU to signal positive or negative acknowledgements to the sender.

3) Security Sublayer: The security sublayer provides subscribers with privacy across the FBWA network by encrypting connections between SS and BS. An authenticated client/server key management protocol (including digital-certificated based SS authentication) is employed in which the BS controls the distribution of key material to a client SS.

B. Physical Layer (PHY)

The HIPERMAN PHY uses orthogonal frequency division multiplex (OFDM) with a 256 point transform, designed for NLOS operation in the 2 – 11 GHz frequency bands, both licensed and license-exempt. TDD and FDD variants are defined. Typical channel bandwidths used vary from 1.5 to 28 MHz. Currently there is a second optional air interface specification based on orthogonal frequency division multiple access (OFDMA) with a 2048-point transform.

Since a single harmonized frequency band is not present, [4] recommends that the frequency bands 3.4 – 3.6 GHz; 10.15 – 10.3 GHz and 10.5 – 10.65 GHz should be identified as preferred bands for FBWA. Due to the favourable propagation properties, as well as the suitable amount of low-cost spectrum (license exempt) and available cheap RF technology, [5] chose the frequency band 5.725 – 5.875 GHz.

Link distances, i.e. cell sizes, will vary strongly based on the environment, propagation conditions and antenna gain. The system will support distances between 2 km and 4 km for NLOS and up to 10 km for LOS condition.

The phenomenon of delay spread is due to multipath scattering. In order to avoid inter-symbol interference (ISI) and inter-carrier interference (ICI), a cyclic prefix (CP) is introduced in front of every data part of an OFDM symbol. In the targeted frequency bands radio communication benefits significantly from the ability to operate under obstructed LOS and NLOS conditions. It is therefore necessary to choose a CP larger than the maximum delay spread. Tab. I lists common maximum delay spread values in different types of environment. These delay spread values remain unchanged for any operating frequency above 30 MHz, since the wavelengths become much smaller than human-made architectural structures (recent measurements do confirm the values for frequency bands between 800 MHz and 6 GHz) [6], [7].

TABLE I. Delay Spread

Type of Environment	Max. Delay Spread
In-Building (house, offi ce)	$< 0.1\ \mu$s
Large building (factory, malls)	$< 0.2\ \mu$s
Open Area	$< 0.2\ \mu$s
Suburban Area LOS	0.2–1.0 μs
Non-LOS	0.4–2.0 μs
Urban Area	1.0–3.0 μs

HIPERMAN's forward error correction (FEC) scheme consists of the concatenation of a Reed-Solomon outer code and a rate-compatible convolutional inner code. The Reed-Solomon outer code may be shortened and punctured. Block turbo coding (BTC) is optional for all modes. The FEC options are paired with the modulation schemes listed in Tab. III to form burst profiles of varying robustness and efficiency.

The basic HIPERMAN OFDM parameters are outlined in the first two columns of Tab. II and Tab. III. The additional values in the tables correspond to an exemplary scenario which is presented in section III.

TABLE II. Basic OFDM parameters

OFDM Parameters	Value	Example
Sampling Rate	$7/6 \cdot BW$	$7/6 \cdot 20$MHz
$F_S = 1/T$	$8/7 \cdot BW$	$= 23.33$ MHz
Useful Time T_B	$256 \cdot T$	$10.97\ \mu$s
T_G/T_B	$\frac{1}{4}, \frac{1}{8}, \frac{1}{16}, \frac{1}{32}$	
CP Time T_G		$\frac{1}{4} \cdot 10.3\ \mu s = 2.74\ \mu s$
Symbol Time T_{Sym}	$T_G + T_B$	$13.7\ \mu$s
Carriers N_{FFT}	256	
Data-Carriers	192	

TABLE III. PHY modes and dependent bit rates

Modulation/ Coding	Data Bit/ Symbol	Example PHY Gross Bit Rate	Example MAC Net Bit Rate
QPSK 1/2	192	14.0 Mbit/s	12.7 Mbit/s
QPSK 3/4	288	21.0 Mbit/s	18.9 Mbit/s
16QAM 1/2	384	28.0 Mbit/s	25.2 Mbit/s
16QAM 3/4	576	42.0 Mbit/s	38.0 Mbit/s
64QAM 2/3	768	56.0 Mbit/s	50.5 Mbit/s
64QAM 3/4	864	63.0 Mbit/s	56.9 Mbit/s

III. Performance Evaluation

A. System performance of an example scenario

In this section an exemplary system with 20 MHz bandwidth operating in TDD mode in licensed spectrum bands is evaluated. The frame length is set to 10 ms and a CP of $1/4 \cdot T_B$ is chosen to deal with delay spread values for NLOS operation in suburban areas (refer to Tab. I). Fig. 3 illustrates the MAC frame which is analyzed. The scenario deals with one DL and one UL connection between one BS and one selected SS, which are located 4 km apart. The MAC frame consists of the DL preamble, the FCH, DL-burst#1 and #2, the TTG ($5.14\ \mu$s), four RNG-REQ slots, with the respective round trip delay (RTD, $26.74\ \mu$s) considered for each slot, 10 BW-REQ slots, one UL-preamble, UL-burst #1 and the RTG ($5.14\ \mu$s). The payload was assumed to be Ethernet traffic with a fixed packet size of 1518 byte. These packets are encapsulated into MAC PDUs without being packed or fragmented. ARQ is also disabled.

Resulting values for the basic OFDM parameters can be observed in Tab. II. Based on these values gross bit rates on PHY level ($\mathrm{bit_{sym}/T_{sym}}$) between 14 and 63 Mbit/s can be realized depending on the chosen PHY mode (see Tab. III).

To get the resulting system throughput the overhead must be subtracted. Thus all frame elements which do not contain payload have been taken off (white and light grey parts of

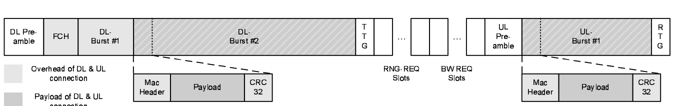

Fig. 3. MAC frame of scenario

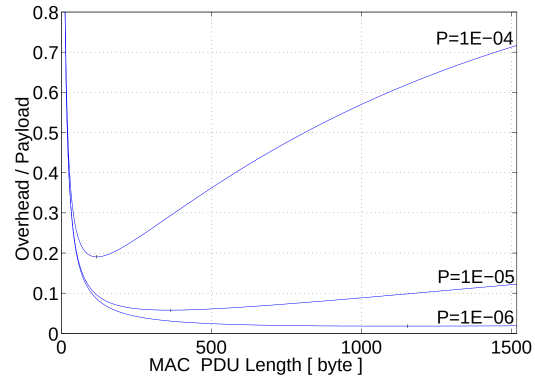

Fig. 4. Optimum MAC PDU length with rest bit errors

Fig. 3). Remaining is the payload of the MAC PDUs. Now the net bit rate on MAC level can be calculated to values ranging from 12.7 to 56.9 Mbit/s (see Tab. III). Approximately 89.5% of the gross bit rates on PHY level is available to higher layers, or in other words the PHY and the MAC protocol reduces the bit rate by 10.5% due to overhead.

B. Optimal MAC PDU configuration

Two optional features of the HIPERMAN standard have not been considered in the evaluation of the system performance above, which are ARQ and packing/fragmentation. Both features have to be considered while efficiently filling the MAC frame with data.

The packet length of incoming traffic may vary significantly between 53 byte for ATM cells, up to 1518 byte for Ethernet traffic and up to 65535 byte for TCP/IP packets. These packets may be fragmented and/or packed into the MAC PDU payload. Encapsulating the data in MAC PDUs means adding additional overhead, i.e. headers and CRC. As the payload increases, the ratio overhead to payload decreases for the error free transmission.

The assumption of rest bit errors leads to an optimum size which is different to the result of the error free case. Rest bit errors introduce additional overhead, since faulty MAC PDUs need to be retransmitted. The larger the MAC PDU, the more data has to be retransmitted when an error occurs.

These two competing effects can now be expressed in the following formulas. The calculation denotes the MAC overhead OH_{mac} and the retransmission overhead OH_{ret}. The variable p signifies the rest bit error rate and N_{mac} the total length of the MAC PDU in bit.

$$OH_{mac} = \frac{header+CRC}{N_{mac}-(header+CRC)}$$

$$OH_{ret} = \frac{\left(1-(1-p)^{N_{mac}}\right)}{(1-p)^{N_{mac}}} \cdot \frac{N_{mac}}{payload}$$

The addition of OH_{ret} and OH_{mac} leads to the overhead in the case of rest bit errors in Fig. 4. The rest bit error rates of 10^{-4}, 10^{-5}, and 10^{-6} lead to optimal MAC PDU sizes of 107, 349 and 1113 byte respectively.

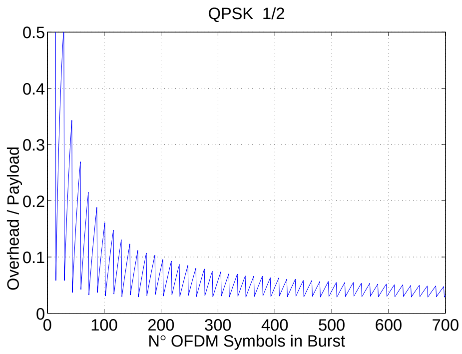

Fig. 5. No fragmentation

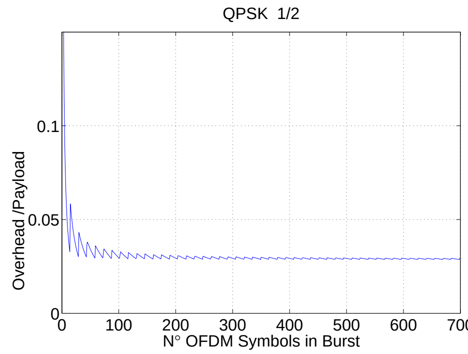

Fig. 6. Enabled fragmentation

Having found an optimal MAC PDU length for every rest bit error rate another effect appears. Several MAC PDUs are concatenated and transmitted in a single burst. A burst is always made up of an integer number of OFDM symbols, i.e. it is filled up with padding bit. Padding overhead becomes more significant in the case of longer MAC PDUs since small ones better fill up the burst. But padding overhead can be avoided by fragmenting the last MAC PDU of each burst to the precise length to fill up the burst. For the exemplary scenario the number of OFDM symbols per MAC frame (10ms) is 730. Normally there are several bursts within one frame so the size of a single burst will be much smaller than 700. Fragmentation is enabled and all incoming data packets are fragmented to the optimal size of 349 byte for a rest bit error rate of 10^{-5}. Thus the MAC PDU length is fixed. Overhead due to retransmissions is neglected in the following.

Fig. 5 illustrates the ratio overhead to payload over the burst length without fragmenting the last MAC PDU. The graph shows a sawtooth-like shape. The size of the teeth increases with decreasing length of the overall burst, i.e. the less OFDM symbols there are within a burst, the more significant the padding overhead gets. Having a small burst length ratios of over 30% can be observed.

Fig. 6 shows the same scenario but now the last MAC PDU of each burst is fragmented that it fits perfectly into the burst. Thus the overhead due to padding is avoided. Only the additional fragmentation overhead is still there. Especially for burst lengths below 100 OFDM symbols, it is advisable to fragment the last PDU to fill the burst.

The graphs are examples for PHY mode QPSK 1/2. Although the significance of fragmentation to avoid padding decreases with higher PHY modes, fragmentation in general is still recommended to minimize the MAC overhead due to MAC header / CRC fields and retransmissions. Especially when having small bursts, the adaptive fragmentation of the last PDU of each burst is suggested to avoid padding. If small MAC PDU payloads and only a small number of MAC PDUs per burst need to be transmitted, it is unnecessary to use high order modulation schemes since they will be filled up with padding bit.

IV. Conclusion

This paper presents an overview of the HIPERMAN protocol and a first performance evaluation of the standard by theoretical means. Details of the MAC and the PHY layer are discussed and it elaborates on important points, such as the MAC frame structure and packing, fragmentation and ARQ algorithms. The MAC PDU configuration is analyzed in the context of throughput, overhead, packing and fragmentation. We figured out that overall MAC overhead of the HIPERMAN system can be assumed to approximately be 10%. However, the achievable bit rates are sufficient to provide FBWA to potential customers even in a challenging NLOS scenario. Further on it has been shown that the optional features packing and fragmentation are powerful to optimize the system throughput while several active connections are sharing the MAC frame in the presence of rest bit errors.

V. Acknowledgments

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