# Structure and Performance of the HIPERLAN/2 Physical Layer

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*Abstract* — **At present, standards for broadband wireless multimedia communications in the 5 GHz band are being developed in Europe as well as in the U.S. and Japan. HIPERLAN/2 is an upcoming standard which is being specified by the ETSI Project BRAN and is intended to be finished in April 2000. The physical layers of the three systems will be well harmonized whereas the upper layer protocols are different. In this paper, the concepts and parameters of the physical layer of HIPERLAN/2 are described. According to the harmonization with the American and the Japanese system similarities and differences are pointed out. Furthermore, exemplary performance results are included and discussed.**

## I. INTRODUCTION

Massive growth in wireless and mobile communications, the emergence of multimedia applications as well as high-speed Internet access and the deregulation of the telecommunications industry are the key drivers towards a new demand for radio-based broadband access networks.

The ETSI Project BRAN (Broadband Radio Access Networks) focuses on standards for different types of wireless broadband access networks. One of these systems called High PErformance Radio Local Area Network type 2 (HIPERLAN/2) shall provide high-speed communications (with a bit rate of at least 20 Mbps) between mobile terminals and various broadband infrastructure networks.

In the U.S., a high-speed physical layer is being developed to extend IEEE802.11 which will re-use the MAC layer already defined. The respective system in Japan will have three different upper layer protocols for three different services, but it will be based on a common physical layer.

The three systems in Europe, the U.S. and Japan will operate in the 5 GHz band. The frequency allocations are depicted in Fig. 1. It should, however, be noted that the allocation is not yet decided in Europe. Therefore, the frequency bands given for Europe are actually those which are being considered for HIPERLAN/2.

All three physical layers will be harmonized to a large extent, hence, providing a worldwide platform for broadband wireless multimedia communications.

Due to the limited length of this paper, it is apparently not possible to describe all features of the considered standards. Rather, the key functionality and performance are highlighted.

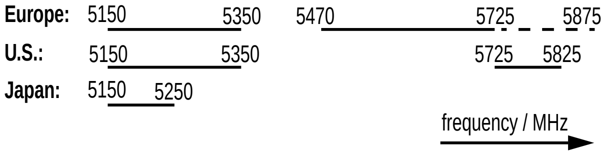

Figure 1: Frequency allocation in Europe, the U.S. and Japan

## II. PHYSICAL LAYER OF HIPERLAN/2

In the HIPERLAN/2 standard, a radio subsystem for broadband wireless multimedia communications is specified, which can be used with a variety of services and protocols. This is possible due to the flexible architecture, which defines a convergence layer between these upper layer protocols and the data link control (DLC) layer of HIPERLAN/2. The convergence layers currently under consideration are designed for IP (Internet protocol), ATM (asynchronous transfer mode), UMTS (universal mobile telecommunications systems) interworking, and IEEE 1394 (FireWire). The data units which are transmitted within these protocols may be different in length, type and content. The convergence layer in HIPERLAN/2 segments these data units into user protocol data units (U-PDUs) with fixed length of 54 bytes, which are transmitted through the data link control (DLC) and physical layer.

Other PDUs are used for controlling the radio subsystem internally. The PDUs in the broadcast control channel and the frame control channel comprise 12 bytes and multiples of 27 bytes, respectively. Furthermore, control PDUs (C-PDUs) with a length of 9 bytes carry information for traffic channel control like acknowledgments.

HIPERLAN/2 is a cellular system which is controlled by an access point (AP, equivalent to a base station). There are two modes of operation. In the centralized mode, mobile terminals (MTs) communicate through the AP with other MTs or the network. In the direct mode, there are links between MTs. In all cases, the APs assign radio resources and control communications in the cells. Some further system and network aspects can be found in [7].

The air interface of HIPERLAN/2 is based on time-division duplex and dynamic time-division multiple access. There is a basic frame with fixed length, which comprises five fields for broadcast control, frame control, downlink, uplink and random access as depicted in Fig. 2. In all cases, the transmission format on the physical layer is a burst, which consists of a preamble and a data field. The latter comprises a train of C-PDUs and U-PDUs to be transmitted or received by one MT.

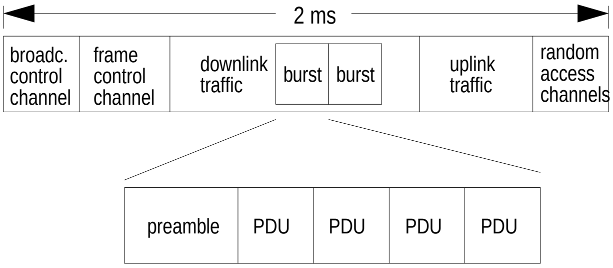

Figure 2: Frame structure of HIPERLAN/2

Orthogonal frequency division multiplexing (OFDM), which has been investigated e.g. in [6,8], has been selected as modulation scheme for HIPERLAN/2 due to its good performance on highly dispersive channels. A comparison with single-carrier modulation showing the superiority of OFDM for this application is presented in [2].

The channel raster is equal to 20 MHz to provide a reasonable number of channels in 100 MHz bandwidth which may be the narrowest continuous system bandwidth available, for instance, in Japan. In order to avoid unwanted frequency products in implementations the sampling frequency is also chosen equal to 20 MHz at the output of a typically used 64-point IFFT. The obtained subcarrier spacing is 312.5 kHz. In order to facilitate implementation of filters and to achieve sufficient adjacent channel suppression, 52 subcarriers are used per channel. 48 subcarriers carry actual data and 4 subcarriers are pilots which facilitate phase tracking for coherent demodulation. The duration of the cyclic prefix is equal to 800 ns, which is sufficient to enable good performance on channels with (r.m.s.) delay spread up to 250 ns (at least).

A key feature of the physical layer is to provide several physical layer modes with different coding and modulation schemes, which are selected by link adaptation. BPSK, QPSK and 16QAM are the supported subcarrier modulation schemes. Furthermore, 64QAM can be used in an optional mode.

Forward error control is performed by a convolutional code of rate 1/2 and constraint length seven. The further code rates 9/16 and 3/4 are obtained by puncturing. The modes are chosen such that the number of encoder output bits fits to an integer number of OFDM symbols. To additionally accommodate tail bits appropriate dedicated puncturing before the actual code puncturing is applied. The obtained coding and modulation scheme is bit-interleaved coded modulation, which has been investigated in [9] for 8PSK.

Seven physical layer modes are specified, of which the first six are mandatory and the last one based on 64QAM is optional:

Table 1: Physical layer modes of HIPERLAN/2

| Mode | Modulation | Code rate | Physical layer bit rate |
|---|---|---|---|
| 1 | BPSK | 1/2 | 6 Mbps |
| 2 | BPSK | 3/4 | 9 Mbps |
| 3 | QPSK | 1/2 | 12 Mbps |
| 4 | QPSK | 3/4 | 18 Mbps |
| 5 | 16QAM | 9/16 | 27 Mbps |
| 6 | 16QAM | 3/4 | 36 Mbps |
| 7 | 64QAM | 3/4 | 54 Mbps |

## III. PREAMBLES

The units which are processed on the physical layer are bursts comprising a preamble and PDU trains. Three different preambles are used for (i) the broadcast control channel, (ii) other downlink channels, (iii) the uplink and the random access channel.

The preamble in the broadcast control channel enables frame synchronization, automatic gain control, frequency synchronization as well as channel estimation. In contrast, the preamble in the downlink traffic bursts needs to be designed for channel estimation only. The uplink traffic bursts and the random access bursts have to enable channel estimation and frequency estimation. Consequently, there are several preambles with different structures and lengths as depicted in Fig. 3.

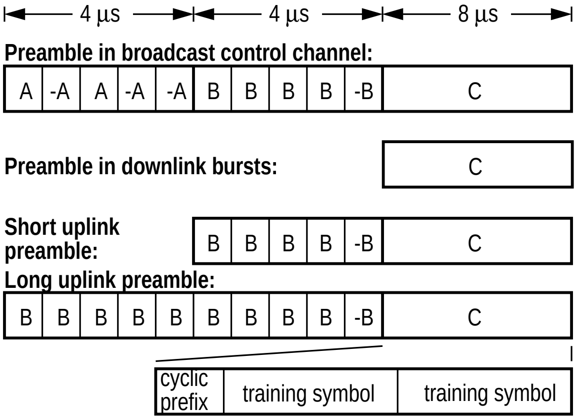

Figure 3: Structure of preambles of HIPERLAN/2

The A and B symbols, which are different, comprise 16 time-domain samples each. The symbols denoted by -A and -B are negative replica of A and B, respectively.

The block of four symbols A,-A,A,-A can be generated by a 64-point IFFT from a frequency-domain symbol with 12 used subcarriers at the frequency indexes +/-2, +/-6, ... The additional -A symbol is appended by repetition in time domain. The B symbols are generated equivalently from a frequency-domain symbol with used subcarriers at the indexes +/-4, +/-8, ...

Due to the time-domain structures of the sequences A,-A,A,-A and B,B,B,B broadcast control channels and uplink bursts can be easily distinguished. The appended -A and -B symbols are intended to provide improved timing estimation.

The C part, which is included in every preamble, comprises two training symbols, which use 52 subcarriers, and a cyclic prefix of 1.6 µs. The C part is intended to be used for channel estimation, whereas the previous short symbols shall be used for all other purposes like frame synchronization, frequency estimation, etc.

There are two uplink preambles, which can be chosen by the AP depending on its receiver capabilities. Both preambles are mandatory for the MT.

Frame synchronization performance is characterized by the detection failure probability and false alarm probability. Both are depicted in Fig. 4 for a scenario with signal-to-noise ratio equal to 5 dB, and a highly-dispersive channel with 250 ns delay spread (channel model E introduced in the next section, cf. Table 2). The frequency offset is equal to –240 kHz according to the +/-20 ppm accuracy requirement for the frequency source. The chosen parameters are seen as the worst case for a HIPERLAN/2 system. It turns out that even in this situation frame synchronization succeeds with a probability of 96%.

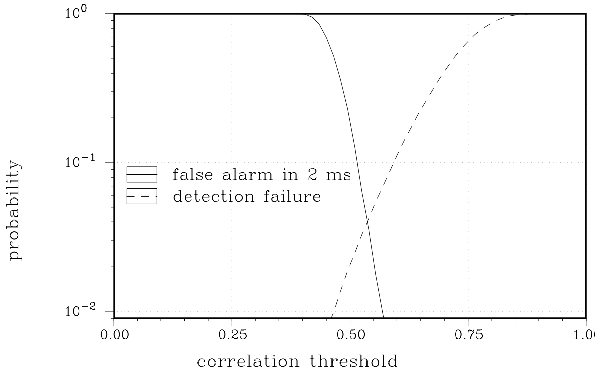

Figure 4: Detection failure and false alarm probability for frame synchronization based on preamble in broadcast control channel, signal-to-noise ratio 5 dB, channel model E (cf. Table 2)

This example and other results not included here demonstrate that HIPERLAN/2 provides the means for robust and fast synchronization. This feature is important to guarantee, for instance, fast call set-up and handover as well as short wake-up times.

## IV. LINK PERFORMANCE

Exhaustive simulations have been conducted for selection of parameters and performance analysis during the standardization process. Some exemplary results are included below.

The main performance measure in this context is the PDU error rate (PER) in the presence of noise and co-channel interference. Channel models have been developed for standardization [1,4], see the key parameters listed in Table 2. They were derived from measurements in typical indoor and outdoor environments [3].

Table 2: Parameters of channel models

| Name | r.m.s. delay spread | Rice factor on 1st tap | Environment |
|---|---|---|---|
| A | 50 ns | - | office NLOS (no line of sight) |
| B | 100 ns | - | open space / office NLOS |
| C | 150 ns | - | large open space NLOS |
| D | 140 ns | 10 dB | large open space LOS |
| E | 250 ns | - | large open space NLOS |

The power delay profiles are exponentially decaying. The channel taps are statistically independent and complex Gaussian distributed with zero mean (except for the Ricean one). For the simulations below, it has been assumed that the impulse responses for subsequent bursts are statistically independent.

The simulations are carried out with running frequency, timing, and channel estimation. Error rate performance at the presence of a co-channel interferer is depicted in Fig. 5 for all modes on channel model A. It is given in terms of PER as a function of C/I which denotes signal-to-interference power ratio.

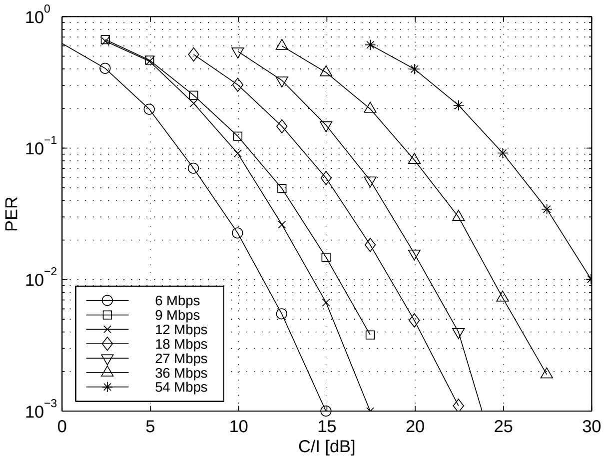

Figure 5: PDU error rate vs. C/I for channel model A

As expected the C/I required for a certain error rate increases with provided bit rate. Only the 9 Mbps mode behaves differently with worse performance than the 12 Mbps mode. Hence, it may typically not be used in practice. The reason for this behavior is that frequency diversity is exploited by the convolutional code; and the worse performance of the rate-3/4 code compared to the rate-1/2 code is the dominating effect in terms of C/I performance rather than the lower bit rate.

Interestingly, there is no visible error floor for the high bit rate modes even though the major channel and receiver impairments are taken into account. This shows a clear advantage of OFDM which hence provides robustness for systems with link adaptation even in the presence of time-dispersive channels as long as the channel excess delay does not significantly exceed the length of the cyclic prefix.

A reasonable point of operation for packet services without delay constraint may lie between PERs of 1% and 10%. The respective C/I requirement is, therefore, between 7 dB and 30 dB depending on the mode.

Noise sensitivity is depicted in Fig. 6 for all modes on channel model A. It is given in terms of PER as a function of $E_b/N_0$, which denotes the ratio of energy per physical layer input bit and noise power density.

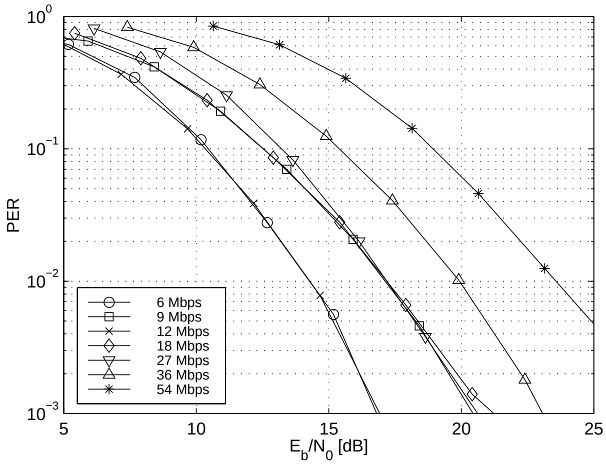

Figure 6: PDU error rate vs. $E_b/N_0$ for channel model A

As expected BPSK and QPSK have the same $E_b/N_0$ requirement. The performance of the rate-3/4 code shows a remarkable degradation compared to the rate-1/2 code, which is due to the considerable frequency selectivity of the channel. Interestingly, the modes with 9 Mbps, 18 Mbps and 27 Mbps perform almost equal in this context. Hence, the penalty for increasing code rate from 1/2 to 3/4 on the considered channels is approximately the same as for changing modulation from BPSK or QPSK to 16QAM while keeping code rate 1/2.

HIPERLAN/2 will support a variety of services. The one which may be used frequently is packet data transmission without delay constraint. A selective-repeat ARQ scheme has been chosen for error control. A simple approximation of the ideally achievable link throughput in terms of Mbps for a mode with bit rate *r* [Mbps] is given by *r* (1 - PER). The respective results for all modes are depicted in Fig. 7 as a function of C/I.

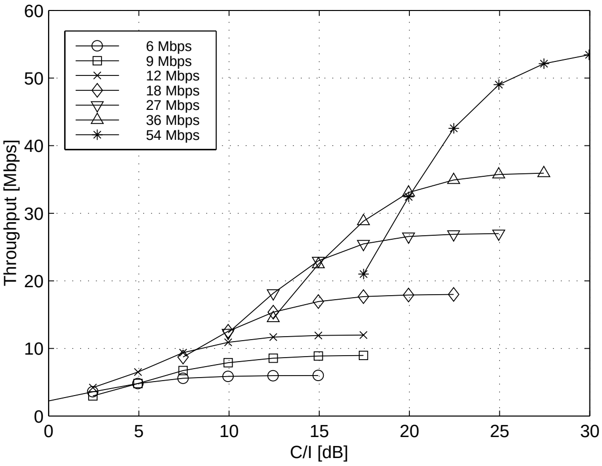

Figure 7: Link throughput vs. C/I for channel model A

In case of perfect link adaptation, the mode with highest throughput would be chosen for each instantaneous C/I. Hence, the maximum of these curves is the link throughput for ideal link adaptation.

## V. ADJACENT CHANNEL SUPPRESSION

Interference studies in cellular systems with high load show that an adjacent channel interferer should be suppressed at least by 25...30 dB compared to a co-channel interferer in order to not degrade average system throughput remarkably in typical situations and environments. This requirement affects, for instance, the specification of the spectrum mask in neighboring channels.

The implications on the physical layer were investigated based on the model of a class-AB power amplifier in [5]. It turned out that the adjacent channel suppression requirement given above can be fulfilled for all modes if the power amplifier back-off is about 5 dB, which is only by about 2...3 dB higher than for typical single-carrier modulation schemes. It can, therefore, be concluded that the efficiency of power amplifier, which is a typically used argument against OFDM, is not that important in HIPERLAN/2. And it is more than balanced by its benefits as already discussed in [2].

## VI. STANDARDS BY IEEE AND MMAC

In parallel to BRAN, IEEE specifies a high bit rate physical layer for the wireless LAN standard 802.11, which will be well harmonized with the physical layer of HIPERLAN/2. The upper layers, however, will be based on totally different concepts. One of the manifold differences is that IEEE802.11 uses carrier sense multiple access with collision avoidance whereas HIPERLAN/2 will perform centralized resource allocation. These differences in the protocol, however, require some adaptations on the physical layer. The most obvious one is the preamble specification. Since a single packet type is transmitted via the IEEE802.11 physical layer, only one preamble is needed, whose structure is depicted in Fig. 8. It appears to be similar to the long uplink preamble of HIPERLAN/2; it does, however, not include the symbol -B at the end. Since the preamble structure and the symbol lengths are the same for both standards, harmonization is still guaranteed.

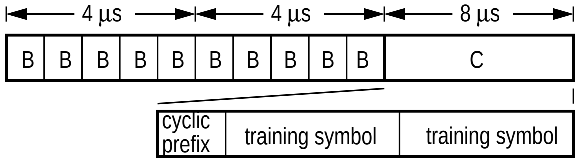

Figure 8: Structure of IEEE802.11 preamble

Another deviation of HIPERLAN/2 and IEEE802.11 appears with regard to the physical layer modes. IEEE802.11 does not include the mode with 27 Mbps; instead there is one with 24 Mbps. Also, an additional mode with 48 Mbps is foreseen in IEEE802.11. These minor differences are due to the granularity given by one OFDM symbol. The specification of the HIPERLAN/2 modes is appropriate for given PDU sizes whereas almost arbitrary Ethernet packet length may exist in IEEE802.11.

The standard which is currently being specified by MMAC actually comprises three different standards. One will be very similar to IEEE802.11. The second one will use protocols very similar to HIPERLAN/2. However, since it shall be based on the same physical layer as the IEEE802.11 like standard, there will be again some minor differences to HIPERLAN/2, for instance, with regard to preambles.

## VII. CONCLUSIONS

In this paper, the key features and parameters of the HIPERLAN/2 physical layer have been presented. It has been shown to be an efficient and flexible platform for broadband services, which will provide physical layer input bit rates up to mandatory 36 Mbps or optionally even up to 54 Mbps within a 20 MHz wide channel.

The performance results illustrate the high power efficiency, robustness and flexibility of the selected coding and modulation schemes, which are based on convolutional coding and OFDM. It has been demonstrated that this is well suited to support link adaptation for a wide range of channel conditions. For instance, delay spreads of up to 250 ns (at least) can be coped with, which is sufficient for operation in typical outdoor environments with cell radii of at least 100 m.

HIPERLAN/2 systems will operate in the 5 GHz band, which is seen as a fair compromise between availability of wide frequency bands and still reasonable cell sizes. Although the spectrum assignment in Europe is not yet settled, the current status promises the availability of a number of channels which is sufficient to build high-capacity systems.

Finally, the similarities to other standards by IEEE and MMAC have been described. It turned out that the well harmonized physical layers of the three standards open the door for future broadband communications in the 5 GHz band almost worldwide.

## VIII. REFERENCES

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