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A Comparison of HIPERLAN/2 and IEEE 802.11a Physical and MAC Layers

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Abstract

At present, Wireless Local Area Networks (WLANs) supporting broadband multimedia communication are being developed and standardized. Two such standards are HIPERLAN/2, defined by ETSI BRAN and the IEEE's 802.11a. These WLAN standards will provide data rates up to 54 Mbps (in a channel spacing of 20 MHz) in the 5.2GHz band. In this paper an overview of the two standards is presented together with software simulated physical layer performance results for each of the transmission modes defined in the two standards. Furthermore, the differences between the standards (PDU size, upper protocol layers etc.) and the effects on applications are discussed.

1. Introduction

Wireless Local Area Networks (WLANs) provide wideband wireless connectivity between PCs, laptops, and other equipment within a building. WLANs also offer an easy way of setting up computer networks by avoiding the need for cable installation.

The two standards HIPERLAN/2 [1] defined by ETSI BRAN and the IEEE's 802.11a [2] will each support multiple transmission 'modes', providing data rates up to 54 Mbps where channel conditions permit. Thus, both standards will offer the throughput that is necessary to meet the requirements for multimedia applications, as well as high speed Internet and Intranet access.

Close cooperation between ETSI and IEEE has ensured that the physical layers of the two standards are harmonized to a large extent. The large scale US and European markets and the harmonization of the physical layers should facilitate low cost production of devices conforming to either standard. As a result, both standards have received considerable industrial backing (e.g. the HIPERLAN/2 Global Forum [9]) and look set to dominate the future of WLAN technology in the 5GHz band.

This paper compares the HIPERLAN/2 and 802.11a standards and identifies their similarities and differences. The two standards differ primarily in the Medium Access Control (MAC) [6,7] but some differences also occur in the physical layers.

The HIPERLAN/2 radio network is defined in such a way that there are core independent Physical (PHY) and DLC layers as well as a set of convergence layers (CL) for interworking with Ethernet, PPP-IP, ATM, UMTS, and IEEE 1394 infrastructure [3,4]. IEEE 802.11a defines similarly independent PHY and MAC layers (with the MAC common to multiple PHYs within the 802.11a standard) and a similar approach to network protocol convergence is expected.

This paper is organized as follows: In Section 2, the MACs specified by the two standards are presented. In Section 3, the Physical Layers (PHY) of HIPERLAN/2 and IEEE 802.11a are described and compared. The channel models that have been specified for evaluation of both standards are presented in Section 4. Simulation results are given in Section 5, which show BER and PER performances against E_b/N_0 for the different channels and transmission modes. These results will facilitate an examination and comparison of the performance of the two standards. Section 6 discusses the results and concludes the paper.

2. Medium Access Control

The main differences between IEEE 802.11a (at 5GHz) and HIPERLAN/2 occur in the MAC [6,7]. In HIPERLAN/2 the medium access is based on a TDD/TDMA approach using a MAC frame with a period of 2 ms [7]. The control is centralized to an 'Access Point' (AP) which informs the 'Mobile Terminals' (MTs) at which point in time in the MAC frame they are allowed to transmit their data. Time slots are allocated dynamically depending on the need for transmission resources. IEEE 802.11a uses a distributed MAC protocol based on Carrier

Sense Multiple Access with Collision Avoidance (CSMA/CA) [2,6].

The HIPERLAN/2 and IEEE 802.11a MAC layer are discussed in more detail in sections 2.a and 2.b respectively.

2.a. HIPERLAN/2 MAC [7]

The MAC frame structure (Figure 1) comprises time slots for broadcast control (BCH), frame control (FCH), access feedback control (ACH), and data transmission in downlink (DL), uplink (UL), and directlink (DiL) phases, which are allocated dynamically depending on the need for transmission resources [1,4]. An MT first has to request capacity from the AP in order to send data. This can be done in the random access channel (RCH), where contention for the same time slot is allowed [1].

Figure 1. The HIPERLAN/2 MAC frame

Downlink, uplink and directlink phases consist of two types of PDUs: long PDUs and short PDUs. The long PDUs (Figure 2) have a size of 54 bytes and contain control or user data. The payload is 49.5 bytes and the remaining 4.5 bytes are used for the PDU Type (2 bits), a sequence number (10 bits, SN) and cyclic redundancy check (CRC-24). Long PDUs are referred to as the long transport channel (LCH).

Figure 2: Format of the long PDUs

Short PDUs contain only control data and have a size of 9 bytes. They may contain resource requests, ARQ messages etc. and they are referred to as the short transport channel (SCH).

Traffic from multiple connections to/from one MT can be multiplexed onto one PDU train, which contains long and short PDUs. A physical burst (Figure 3) is composed of the PDU train payload and a preamble and is the unit to be transmitted via the physical layer [1].

Figure 3: HIPERLAN/2 Physical Burst Format

2.b. IEEE 802.11 MAC [2]

As stated earlier IEEE 802.11 uses a distributed MAC protocol based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). A mobile terminal must sense the medium for a specific time interval and if the medium is idle it can start transmitting the packet [2,6]. Otherwise the transmission is deferred and a backoff process begins, which means that the terminal has to wait for a time interval. Once the backoff time has expired, the terminal can access the medium again [10]. Because a collision in a wireless environment is undetectable, a positive acknowledgement is used to notify that a frame has been successfully received. If this acknowledgement is not received the terminal will retransmit the packet.

Figure 4 shows the format of a complete packet (PPDU) in 802.11a, including the preamble, header and Physical Layer Service Data Unit (PSDU or payload).

Figure 4: PPDU Frame Format [2]

The header contains information about the length of the payload and the transmission rate, a parity bit and six zero tail bits. The header is always transmitted using the lowest rate transmission mode in order to ensure robust reception. Hence, it is mapped onto a single BPSK modulated OFDM symbol.

The rate field conveys information about the type of modulation and the coding rate used in the rest of the packet.

The length field takes a value between 1 and 4095 and specifies the number of bytes in the PSDU.

The parity bit is a positive parity for the first seventeen bits of the header.

Figure 5: HIPERLAN/2 & IEEE 802.11a Transmitter

The six tail bits are used to reset the convolutional encoder and to terminate the code trellis in the decoder.

The first 7 bits of the service field are set to zero and are used to initialize the descrambler. The remaining nine bits are reserved for future use.

The pad bits are used to ensure that the number of bits in the PPDU maps to an integer number of OFDM symbols.

3. Physical Layer (PHY) of HIPERLAN/2 and IEEE 802.11a

The physical layers of both standards are very similar and are based on the use of Orthogonal Frequency Division Multiplexing (OFDM). OFDM is used to combat frequency selective fading and to randomize the burst errors caused by a wideband fading channel [8]. The physical layer modes (Table 1) with different coding and modulation schemes are selected by a link adaptation scheme [3,4]. The exact mechanism of this process is not specified in the standard. Figure 5 shows the reference configuration of the transmitter.

Data for transmission is supplied to the physical layer in the form of an input PDU train as mentioned in the previous section.

The PDU train is input to a scrambler that prevents long runs of 1s and 0s in the input data being input to the remainder of the modulation process. Although both 802.11a and HIPERLAN/2 scramble the data with a length 127 pseudo random sequence, the initialization of the scrambler is different.

The scrambled data is input to a convolutional encoder. The encoder consists of a $\frac{1}{2}$ rate mother code and subsequent puncturing. The puncturing schemes facilitate the use of the code rates: $\frac{1}{2}$, $\frac{3}{4}$, $\frac{9}{16}$ (HIPERLAN/2 only) and $\frac{2}{3}$ (802.11a only). In the case of 16-QAM, HIPERLAN/2 uses rate $\frac{9}{16}$ instead of rate $\frac{1}{2}$ in order to ensure an integer number of OFDM symbols per PDU train. The rate $\frac{2}{3}$ is used only for the case of 64-QAM in 802.11a. Note that there is no equivalent mode for HIPERLAN/2. HIPERLAN/2 also uses additional puncturing in order to keep an integer number of OFDM symbols with 54 byte PDUs.

The coded data is interleaved in order to prevent error bursts from being input to the convolutional decode process in the receiver.

The interleaved data is subsequently mapped to data symbols according to either a BPSK, QPSK, 16-QAM or 64-QAM scheme. The OFDM modulation is implemented by means of an inverse FFT. 48 data symbols and 4 pilots are transmitted in parallel in the form of one OFDM symbol.

Numerical values for the OFDM parameters are given in Table 2. In order to prevent ISI, a guard interval is implemented by means of a cyclic extension. Thus, each OFDM symbol is preceded by a periodic extension of the symbol itself. The total OFDM symbol duration is $T_{total} = T_g + T$ where T_g is the guard interval and T is the useful symbol duration. When the guard interval is longer than the excess delay of the radio channel, ISI is eliminated [11].

The OFDM receiver basically performs the reverse operations of the transmitter. However, the receiver is also required to undertake AGC, time and frequency synchronization and channel estimation. Training sequences are provided in the preamble for the specific purpose of supporting these functions. Two OFDM symbols are provided in the preamble in order to support the channel estimation process. A priori knowledge of the transmitted preamble signal facilitates the generation of a vector defining the channel estimate, commonly referred to as the Channel State Information (CSI).

The channel estimation preamble is formed such that the two symbols effectively provide a single guard interval of length $1.6\mu s$. This makes it particularly robust to ISI. By averaging over two OFDM symbols, the distorting effects of noise on the channel estimation process can also be reduced.

HIPERLAN/2 and 802.11a use different training sequences in the preamble. The training symbols used for channel estimation are the same but those sequences provided for synchronization are different.

Decoding of the convolutional code will typically be implemented by means of a Viterbi decoder.

Table 1: Mode dependent parameters

Mode	Modulation	Coding rate R	Nominal bit rate [Mbit/s]	Coded bits per sub-carrier	Coded bits per OFDM symbol	Data bits per OFDM symbol
1	BPSK	1/2	6	1	48	24
2	BPSK	3/4	9	1	48	36
3	QPSK	1/2	12	2	96	48
4	QPSK	3/4	18	2	96	72
5	16QAM (H/2 only)	9/16	27	4	192	108
5	16QAM (IEEE only)	1/2	24	4	192	96
6	16QAM	3/4	36	4	192	144
7	64QAM	3/4	54	6	288	216
8	64QAM (IEEE only)	2/3	48	6	288	192

4. Channel Models

HIPERLAN/2 and IEEE 802.11a systems will be deployed in a wide range of environments such as offices, industrial buildings, exhibition halls or even home environments. Different channel models have been produced [5] for the different environments. Table 3 summarizes the channel models that were specified for the two standards [5] and also used to perform the simulations presented in this paper. The channels are wideband, with Rayleigh or Rician modelled tapped delay lines. Each tap suffers independent Rayleigh or Rician fading with a mean corresponding to an exponentially decaying average power delay profile.

Table 2: OFDM Parameters

Parameter	Value
Sampling Rate (f_s)	20 MHz
Useful Symbol Duration (T_U)	3.2 μ s
Guard Interval Duration (T_g)	0.8 μ s
Total Symbol Duration (T_{Total})	4.0 μ s
Number of data sub-carriers (N_D)	48
Number of pilot sub-carriers (N_P)	4
FFT Size	64
Sub-carrier spacing (Δ_f)	0.3125 MHz
Total Bandwidth (B)	16.875 MHz

5. Simulation Results

Performance results have been obtained for a number of different modes for the channels specified for the two standards (Table 3). For each channel model, 2000

uncorrelated wideband Rayleigh channels were generated in order to be convolved with the modulated data.

Table 3: Channel Models

Name	RMS delay spread	Characteristic	Environment
A	50 ns	Rayleigh	Office NLOS
B	100 ns	Rayleigh	NLOS
C	150 ns	Rayleigh	NLOS
D	140 ns	Rice	LOS
E	250 ns	Rayleigh	NLOS

The performance measures in the simulations are the packet (PDU or PSDU) error rate (PER) and the bit error rate (BER) versus average E_b/N_0 . In all the simulations Hard Decision Viterbi decoding was used. If Soft Decision decoding had been used, a performance gain of 2.5dB would be expected. However, the Soft Decision Viterbi decoder would be more computationally expensive.

5.a. HIPERLAN/2 Performance Results

Figures 6 and 7 present the performances of the different modes of HIPERLAN/2 versus average E_b/N_0 for channel model A. Channel model A is typical for large office environments with non-line-of-sight propagation.

From Figure 6 it can be seen that modes 1 and 3 (BPSK and QPSK $\frac{1}{2}$ rate) have the same E_b/N_0 requirements. The degradation in the performance in mode 2 (BPSK $\frac{3}{4}$) is due to the fact that the punctured convolutional code can not cope with the lack of frequency diversity of channel A. The large and deep fades in the frequency domain can hardly be corrected with the code. This can also be seen from modes 2,4 and 5. The $\frac{3}{4}$ punctured modes 2 and 4 (BPSK and QPSK $\frac{3}{4}$) have the

same performance with mode 5 (16-QAM 9/16 $\approx$ 1/2). Hence, approximately the same degradation in performance results from increasing the code rate or changing the modulation scheme. The similar performance of QPSK 3/4 rate and 16-QAM 1/2 rate is due to the fact that the latter is able to tolerate more erroneous subcarriers, which compensates the smaller distance between constellation points [8].

Figure 6: PER Performance for HIPERLAN/2 (Channel Model A)

Figure 7: BER Performance for HIPERLAN/2 (Channel Model A)

Figures 8 and 9 show simulated PER and BER performances versus mean E_b/N_0 for mode 4 for all the specified channels.

It can be seen that as the delay spread increases the performance is improved until the delay spread becomes so large that ISI and ICI become limiting factors (channel E). Channels B, C and D have increasingly better

performances than channel A due to the increased frequency diversity of the channels. As expected channel D has slightly better performance than channel C because it is modelled as a Rician channel. In channel E the excess delay (1760ns) of the channel is much larger than the guard interval (800ns) so ISI cannot be completely eliminated.

Figure 8: PER Performance of Mode 4 for the Specified Channel Models A-E

Figure 9: BER Performance of Mode 4 for the Specified Channel Models A-E

5.b. IEEE 802.11a Performance Results

Figures 10 and 11 present the performances of modes 3, 4, 6, 7, and 8 of IEEE 802.11a against E_b/N_0 for channel model A. Note that the PSDU size for all these modes is 256 bytes. As would be expected, the relative performance of these modes for IEEE follows a similar trend as for

HIPERLAN/2. As with HIPERLAN/2, mode 1 will exhibit similar performance to mode 3 and modes 2 and 5 will be similar to mode 4.

Figure 10: PER Performance for IEEE 802.11a (Channel Model A)

Figure 11: BER Performance for IEEE 802.11a (Channel Model A)

It can be observed that the BER performance of the two standards are the same. This is expected due to the similarity of the PHY layers and the common mode parameters. The PER performances of the two standards are different. This is due to the different packet sizes used in the simulations (54 bytes for HIPERLAN/2 and 256 bytes for 802.11a). The IEEE 802.11a results also include mode 8 which has no equivalent in HIPERLAN/2. The PER performance of this mode lies between modes 6 and 7. At higher E_b/N_0 the performance of mode 8 is similar

to that of mode 6. However, mode 8 offers an additional 12Mbit/s data rate. This is again due to the lower rate code offsetting the additional E_b/N_0 requirement of the larger constellation size. Thus for values of E_b/N_0 where HIPERLAN/2 would use mode 6, IEEE 802.11a will exhibit a performance advantage. It should be noted that these conclusions might only apply in the case of channels with lower delay spread.

Figure 12: PER Performance of Mode 4 for different PSDU sizes (Channel Model A)

Figure 12 presents the PER performance of mode 4 for different PSDU lengths. As can be seen, a larger PSDU size results in an increased E_b/N_0 requirement to maintain the same PER. This is also expected since a longer PSDU is more likely to be in error for a given BER. Note that the BER does not vary as a function of the PSDU size. It can be seen that an increase in PSDU size from 54 bytes to 256 bytes results in an increase in E_b/N_0 requirement of 2dB in order to achieve a PER of 10^{-2} . The difference will be even greater for a PER of 10^{-3} . The performance difference between 16 byte packets and 54 byte packets is even more significant - approximately 3dBs.

The increased E_b/N_0 requirement of the larger PSDU size means that either an increase in transmit power or a change of mode is required in order to maintain PER performance. This has interesting implications on the efficiency of transmission. A larger PSDU has a smaller overhead requirement for the header, signal field, etc and hence is more efficient. However, if the use of a larger PSDU can only be achieved by using a lower transmission mode, efficiency is reduced. Thus the relationship between efficiency and PSDU size is complex and warrants further investigation.

6. Conclusions

Performance results in terms of BER and PER have been presented for both HIPERLAN/2 and IEEE 802.11a standards and for all transmission modes for the case of transmission over channel A. As expected, the BER performances of the two standards are the same. In the case where the PSDU size in IEEE 802.11a differs from the PDU size in HIPERLAN/2, the PER performances of the two standards differ. In IEEE 802.11a, which has variable size PSDUs, results suggest that the PSDU size will have a significant impact on performance. Larger PSDUs will improve efficiency but may result in increased PER or else require the use of lower rate transmission modes. Thus, in order to maximize performance, the PSDU size must be chosen so as to achieve an optimal tradeoff between overhead efficiency and transmission mode. For HIPERLAN/2, which has a fixed length PDU this is not the case. The additional mode supported by IEEE 802.11a will also improve throughput in some scenarios.

Performance results have also been presented for HIPERLAN/2 mode 4 for transmission over channels A, B, C, D and E. These results indicate that the system performance improves as the RMS delay spread increases, until the excess delay significantly exceeds the guard interval length. This characteristic is due to the use of OFDM instead of a single carrier system. OFDM exploits the increased frequency diversity that results from high RMS delay spread. However, when the excess delay exceeds the guard interval length ISI impairs performance.

The results presented in this paper represent a subset of the possible combinations of mode and channel model. Simulation of performance for all channels and all modes may lead to additional conclusions. For example, it has been shown that mode 5 slightly outperforms mode 4 in channel A. This is due to the fact that the 3/4 rate code used in mode 4 does not perform well in channel A due to its relatively low frequency selectivity. The 1/2 rate code used in mode 5 performs sufficiently better so as to more than compensate for the additional Eb/No requirement of 16-QAM relative to QPSK. It would be of interest to determine if this is also the case for the channels with greater delay spread (channels D or E for example).

A more comprehensive simulation of different modes, channels and packet lengths is planned for the future and will doubtlessly lead to better understanding of the HIPERLAN/2 and IEEE 802.11a standards.

References

- [1] ETSI, "Broadband Radio Access Networks (BRAN); HIPERLAN type 2 technical specification; Physical (PHY) layer," August 1999. <DTS/BRAN-0023003> V0.k.
- [2] IEEE Std 802.11a/D7.0-1999, Part11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High Speed Physical Layer in the 5GHz Band.
- [3] J.Khun-Jush, P.Schramm, U.Wachsmann, F.Wenger "Structure and Performance of HIPERLAN/2 Physical Layer," IEEE VTC'99 Fall (Amsterdam), pp. 2667-2671.
- [4] J.Khun-Jush, G.Malmgren, P.Schramm, J.Torsner "Overview and Performance of the HIPERLAN/2 -A Standard for Broadband Wireless Communications," IEEE VTC'00 Spring (Tokyo).
- [5] Medbo, P.Schramm "Channel Models for HIPERLAN/2" ETSI/BRAN document no. 3ERI085B, 1998.
- [6] R.van Nee, G.Awater, M. Morikura, H. Takanashi, M.Webster, K.W.Halford, "New High-Rate Wireless LAN Standards", IEEE Communications Magazine, Vol.37, No.12, December 1999, pp.82-88.
- [7] ETSI, "Broadband Radio Access Networks (BRAN); HIPERLAN Type 2; Data Link Control (DLC) Layer; Part 1: Basic Transport Functions," December 1999. <DTS/BRAN-0020004-1> V0.m
- [8] R.van Nee, R. Prasad, "OFDM for Mobile Multimedia Communications", Boston: Artech House, Dec.1999
- [9] www.hiperlan2.com/web
- [10] G.Anastasi, L.Lenzini, E.Mingozzi "MAC Protocols for Wideband Wireless Local Access: Evolution Toward Wireless ATM", IEEE Personal Communications, October 1998, pp.53-64.
- [11] W.Y.Zou, Y.Wu, "COFDM: an overview," IEEE Trans. Broadcasting, Vol. 41, No 1, March 1995, pp.1-8.