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A Study of the Performance of HIPERLAN/2 and IEEE 802.11a Physical Layers

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Abstract

HIPERLAN/2 and IEEE 802.11a are two Wireless LAN (WLAN) standards which operate in the 5GHz band. In order to support broadband multimedia communications, they can provide data rates up to 54 Mbps. In this paper an overview of the two standards is presented together with software simulated physical layer performance results. Furthermore, the differences between the two standards (PDU size, MAC layers etc.) and the effects on throughput and range are discussed.

1. Introduction

Wireless Local Area Networks (WLANs) provide wideband wireless connectivity between PCs, laptops, and other equipment in corporate, public and home environments.

The two standards, HIPERLAN/2 [1] defined by ETSI BRAN and the IEEE 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 considered 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 [3]. 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 [4]) and look set to dominate the future of WLAN technology in the 5GHz band. Table 1 gives the power spectrum requirements of WLANs for different regions.

The HIPERLAN/2 radio network is defined in such a way that there are core independent Physical (PHY) and Data Link Control (DLC) layers as well as a set of

convergence layers (CL) for interworking with Ethernet, PPP-IP, ATM, UMTS, and IEEE 1394 infrastructure. IEEE 802.11a defines similarly independent PHY and MAC layers (with the MAC common to multiple PHYs within the 802.11 standard) and a similar approach to network protocol convergence is expected.

Table 1: WLAN spectrum overview

Region	A) 5150-6250 MHz	B) 5250-5350 MHz	C) 5470-5725 MHz
USA	U-NII band FCC Part 15 subpart E	U-NII band FCC Part 15 subpart E	Not allowed
Power limit	50 mW indoor only 200 mW	250 mW indoor/outdoor 1W	
Power limit eirp	200 mW		
Licensing	Unlicensed	Unlicensed	
Coexistence/Etiquette	None	None	
Europe	ERC Decision (99)23	ERC Decision (99)23	ERC Decision (99)23
Power limit eirp	200 mW Hiperlan indoor only	200 mW Hiperlan indoor only	1W Hiperlan indoor/outdoor
Licensing	License exempt	License exempt	License exempt
Coexistence/Etiquette	DFS & TPC mandatory	DFS & TPC mandatory	DFS & TPC mandatory
Japan		Under consideration	Not allowed
Power limit eirp	200 mW		
Licensing	Unlicensed	Licensed (FWA)	
Coexistence/Etiquette	None		

This paper is organized as follows: In Section 2, the OFDM frame formats of HIPERLAN/2 and IEEE 802.11a are presented. In Section 3, the PHY layers of two standards are described. The channel models that have been specified for evaluation of both standards are presented in Section 4. Section 5 describes the link adaptation mechanism. Simulation results are given in Section 6, which show PER performances and link throughput results against Carrier-to-Noise ratio (C/N). Section 7 discusses the results and concludes the paper.

2. OFDM Frame Formats

2.1 IEEE 802.11a

Figure 1 shows the format of a complete packet (PPDU) in 802.11a, including the preamble, header and Physical Layer Service Data Unit (PSDU or payload).

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. 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 PDU maps to an integer number of OFDM symbols.

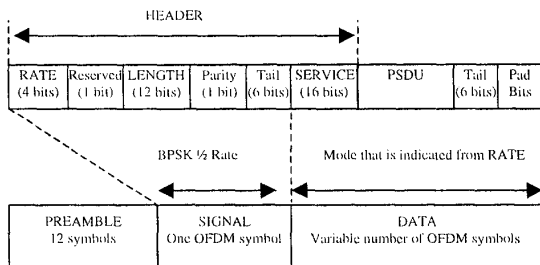


Figure 1: PDU Frame Format

The main difference between IEEE 802.11a and HIPERLAN/2 is in the MAC layer. IEEE 802.11a 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 [5-8].

2.2 HIPERLAN/2

In HIPERLAN/2 the medium access is based on a TDD/TDMA approach using a MAC frame with a period of 2 ms [9]. 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.

The MAC frame structure comprises time slots for broadcast control (BCH), frame control (FCH), access feedback control (ACH), random access channel (RCH), and data transmission in downlink (DL), uplink (UL), and directlink (DiL) phases, which are allocated dynamically depending on the need for transmission resources. 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).

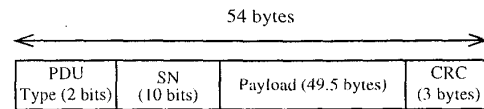


Figure 2: Format of the long PDUs

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).

Figure 3 shows the reference configuration of the transmitter. Data is first input to a scrambler that prevents long runs of 1s and 0s. 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 1/2 rate mother code and subsequent puncturing. The puncturing schemes facilitate the use of the code rates: 1/2, 3/4, 9/16 (HIPERLAN/2 only) and 2/3 (802.11a only). In the case of 16-QAM, HIPERLAN/2 uses rate 9/16 instead of rate 1/2 in order to ensure an integer number of OFDM symbols per PDU train. The rate 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 maintain an integer number of OFDM symbols within its 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.

Table 2: PHY Layer Modes

Mode	Modulation	Coding Rate R	Bit rate [Mbit/s]
1	BPSK	1/2	6
2	BPSK	3/4	9
3	QPSK	1/2	12
4	QPSK	3/4	18
5	16QAM ¹	1/2	24
5	16QAM ²	9/16	27
6	16QAM	3/4	36
8	64QAM ¹	2/3	48
7	64QAM	3/4	54

¹ IEEE 802.11a only, ² HIPERLAN/2 only

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. 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.

The OFDM receiver essentially 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. HIPERLAN/2 and 802.11a use different training sequences in the preamble.

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 [12] for the different environments. Table 3 summarizes the channel models that were specified for the two standards 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 3: Channel Models

Name	RMS delay spread	Characteristic	Environment
A	50 ns	Rayleigh	Office NLOS
B	100 ns	Rayleigh	Open space/Office NLOS
C	150 ns	Rayleigh	Large Open space NLOS
D	140 ns	Rician	Large Open space LOS
E	250 ns	Rayleigh	Large Open space NLOS

5. Link Adaptation with OFDM

The physical layer modes (Table 2) with different coding and modulation schemes are selected by a link adaptation scheme. Link adaptation schemes may use a variety of link quality measurements like PER (Packet Error Rate), received signal strength etc. [11,13].

Each packet (PDU or PPDU) uses CRC-r (Cyclic

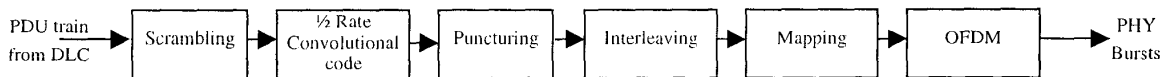


Figure 3: HIPERLAN/2 and IEEE 802.11a Transmitter

Redundancy Check) block codes for error detection, where $r=36$ for IEEE 802.11a and $r=24$ or 16 for HIPERLAN/2. If a packet is detected to be erroneous by the CRC codes (or a positive acknowledgement is not received in IEEE 802.11a) then the terminal will retransmit the packet. In HIPERLAN/2 a selective repeat ARQ scheme has been chosen for error control.

A simple approximation of the link throughput when retransmission is employed is given by: $Throughput = R(1-PER)$, where R and PER are the bit rate and packet error rate for a specific mode respectively. In the case of perfect link adaptation, the mode with the highest throughput would be chosen for each instantaneous C/N value [11,13].

Due to time variations in link quality, the PHY mode is adapted every 5-10 MAC frames for HIPERLAN/2. Measurements of the link quality from both the AP and MT help the AP to select the PHY mode [13].

6. Simulation Results

Figure 4 presents the PER performances of the different modes of HIPERLAN/2 versus the average carrier-to-noise ratio (C/N) for channel model A. Channel model A is typical for large office environments with non-line-of-sight propagation. A reasonable point of operation for packet services without delay constraint may lie between a PER of 1%-10% [11]. The respective C/N requirement is therefore between 7 and 30 dB depending on the mode (see also Figure 6).

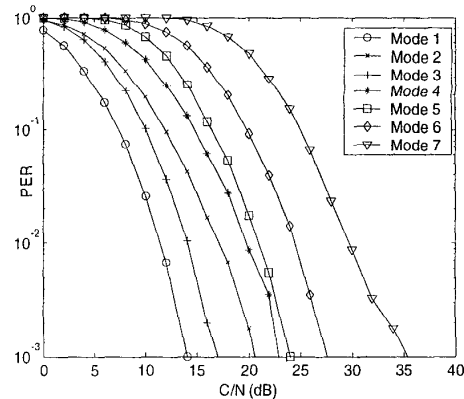


Figure 4: PER Performance for HIPERLAN/2

From Figure 4, it can also be seen that mode 2 (BPSK 3/4) performs worse than mode 3. This

degradation in the performance is due to the fact that the punctured convolutional code cannot cope with the lack of frequency diversity in channel A.

Figure 5 shows simulated PER performances versus C/N for mode 5 for all the specified channels. It can be seen that as the delay spread increases the performance improves in the Rayleigh channels until the delay spread becomes so large that ISI and ICI become limiting factors (channel E). Channels B, C and D have increasingly better performance relative to 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.

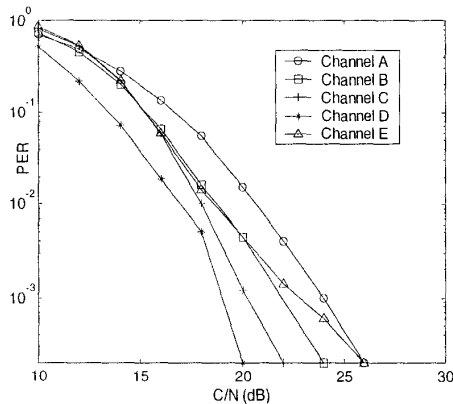


Figure 5: Mode 5 PER Performance

Figure 6 shows the link throughput in HIPERLAN/2 based on Figure 4 and Table 2. The link adaptation mechanism enables the system to adapt the transmission mode to the radio link quality. The mode with the highest throughput is chosen for each instantaneous C/N value.

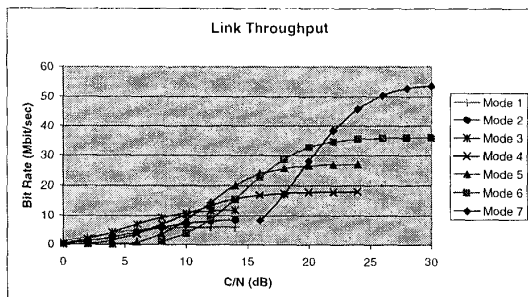


Figure 6: Link Throughput for HIPERLAN/2 (channel model A)

The path loss between an AP and a MT can be calculated with the propagation model shown below:

$$L_p = 10 \log_{10} (4\pi d / \lambda)^2 + \alpha d \quad (1)$$

where d is the distance between the AP and MT, λ is the wavelength and α (dB/m) is fading added to the line of sight path loss to model shadowing effects.

From Table 1 it can be seen that the maximum output power for indoor applications is 200mW=23dBm. If a receiver threshold of -85dBm is assumed, the Max Path Loss (MPL) for reception is given by $MPL = 23 - (-85) = 108$ dB. Figure 7 shows estimated data rates over distance for one AP for $\alpha=0.5$ and 1 respectively, based on equation (1) and the results of Figure 6.

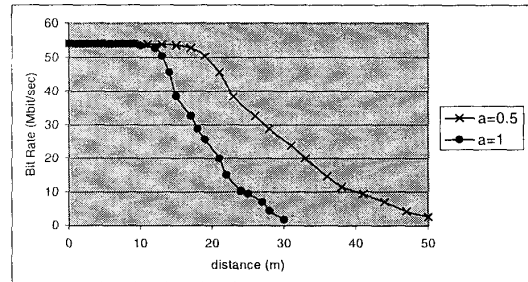


Figure 7: Maximum data rate of HIPERLAN/2 over distance from AP

Figure 8 presents the PER performances of the different modes of IEEE 802.11a versus average carrier-to-noise ratio (C/N) for a PSDU of 512 bytes. These results also include mode 8 (48 Mbits/sec), which has no equivalent in HIPERLAN/2.

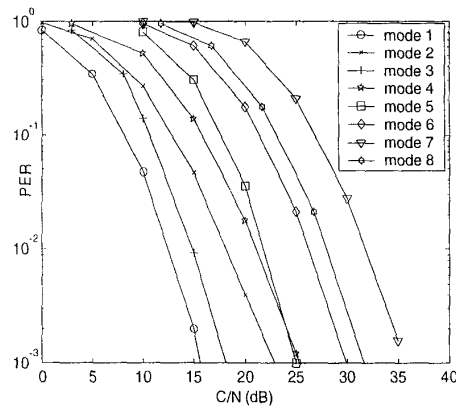


Figure 8: PER Performance for IEEE802.11a

Figure 9 presents the PER performance of mode 6 in IEEE 802.11a for different PSDU lengths. As can be seen, a larger PSDU size results in an increased PER for the same C/N value. This is also expected since a longer PSDU is more likely to be in error for a given BER. Note that IEEE 802.11a and HIPERLAN/2 have the same

BER performances due to their similar PHY layers [5]. It can be seen that an increase in PSDU size from 54 bytes to 512 bytes results in a change in PER performance from 7×10^{-3} to 2×10^{-2} for a C/N value of 25 dB.

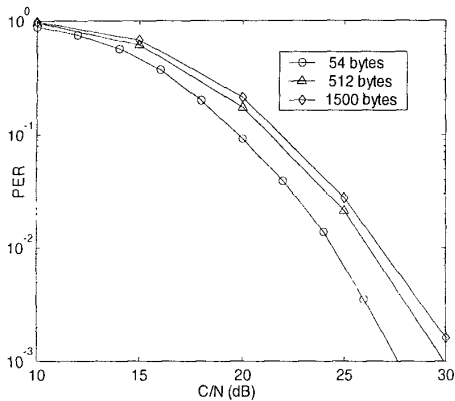


Figure 9: PER Performance of Mode 6 for different PSDU sizes

This has interesting implications on the transmission performance and system throughput. The increased PER of the larger PSDU size results in a reduction of throughput ($Throughput = R(1 - PER)$) for a specific mode and also a change to a lower mode may be required for this C/N value. On the other hand, 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, throughput is reduced. Thus the relationship between efficiency and PSDU size is complex and an IEEE 802.11a system has to adapt both transmission mode and PSDU size in order to provide optimum throughput.

7. Conclusions

This paper presents an overview of the ETSI HIPERLAN/2 and IEEE 802.11a WLAN standards together with physical layer performance results for both standards. The link adaptation mechanism was also described and link throughput results were presented for HIPERLAN/2.

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 overhead efficiency but result in an increased PER. Thus, in order to maximize throughput, 802.11a has to adapt both transmission mode and PSDU size. A detailed analysis of the optimum PSDU size for an IEEE 802.11a can be found in [14].

Finally, the similarities and the differences of the two standards have been described. The link adaptation mechanism employed by the two systems will allow the

throughput to be optimized for the currently available link quality.

In order to obtain the system throughput performance of HIPERLAN/2 and IEEE 802.11a, in addition to the PHY layers, the MAC layers must be examined. The throughput performances of the two standards considering overhead due to preambles, header fields and other MAC parameters can be found in [14].

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