

Diversity techniques for OFDM based WLAN systems: A comparison between hard, soft quantified and soft no quantified decision

Pablo Corral¹, Juan Luis Corral² and Vicenç Almenar²

Universidad Miguel Hernández, Teoría de la Señal y Comunicaciones, Elche, Spain¹.

Universidad Politécnica de Valencia, Dep. Comunicaciones, Valencia, Spain².

e-mail: pcorral@umh.es, {jlcorral, valmenar}@dcom.upv.es

Abstract: This paper presents different spatial diversity techniques that can be employed in an OFDM based WLAN system to improve the system performance in Rice and Rayleigh channels using hard, soft quantified and soft no quantified decision. Packet Error Rate (PER) results are presented for both transmit (up-link) and receive (down-link) diversity configurations. We present some results obtained by simulation when a HIPERLAN/2 transceiver is employed.

1. Introduction

HIPERLAN/2 (HL/2) is a Wireless LAN (WLAN) standard defined by the ETSI BRAN [1]. This standard will operate in the unlicensed 5 GHz band and will provide data rates up to 54 Mbps in the physical layer in order to support broadband multimedia communications between portable devices and different core networks. The centralized mode of HIPERLAN/2 standard controls the communication between different mobile terminals (MTs) by means of fixed access points (APs) which will give service in a specific coverage area in a cellular way.

This paper is focused on the improvements obtained in the quality of data transmission when two or more antennas are used for reception or transmission in a typical indoor multipath channel [2], Rice and Rayleigh channels using hard, soft quantified and soft no quantified decision. Different spatial diversity techniques at the mobile receiver and transmitter have been analysed [3] and assessed by means of simulations of the HIPERLAN/2 physical layer carried out using different kinds of Viterbi decoding.

This paper is organised as follows: Section II describes an overview of the physical layer of the HIPERLAN/2 standard. Section III summarizes hard, soft quantified and soft no quantified decision decoding strategies. Section IV shows different diversity algorithms employed at the receiver and transmitter stage and in Section V analyzes a comparison between the obtained Packet Error Rate (PER) results with and without multiple antennas at receiver, transmitter or both [4] using these Viterbi decoding. Finally, Section VI exposes the conclusions.

2. Overview of Hiperlan/2 physical layer

The physical layer (PHY) of HIPERLAN/2 offers information transfer services to the data link control layer (DLC) of HIPERLAN/2. For this purpose, it provides functions to map different DLC Protocol Data Unit (PDU) trains into framing formats called PHY

bursts. These are appropriate for transmitting and receiving management and user information between an AP and an MT in the centralized mode or between two MTs in the direct mode.

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	16-QAM	9/16	27
6	16-QAM	3/4	36
7	64-QAM	3/4	54

Table 1. Physical layer modes

The air interface of HL/2 is based on time-division duplex (TDD) and dynamic time-division multiple access (TDMA). There is a basic frame with a fixed length of 2 ms, which comprises five phases with variable duration for broadcast and frame control, downlink, direct link (optional), uplink and random access. In all cases, the transmission format on the physical layer is a burst, which consists of a preamble and a data field.

As previously stated, the AP distributes the length of the frame among all phases according to the needs of the system. Orthogonal Frequency Division Multiplexing (OFDM) has been selected as the modulation scheme for HL/2 due to its good performance on highly dispersive channels.

The baseband signal is built using a 64-FFT, and then a cyclic prefix of 16 samples is added to make the system robust to multipath. Since the frequency sampling is 20 MHz, each symbol is 4 μ s (80 samples) length, and the guard interval is 800 ns length. In order to facilitate implementation of filters and to achieve sufficient adjacent channel suppression, only 52 subcarriers are used: 48 are data carriers and 4 are pilots for phase tracking.

This allows uncoded data rates from 12 to 72 Mbps using variable modulation types from BPSK to 64-QAM. As a result, seven different modes with diverse data bit rates are specified for the PHY layer, according to the combination of QAM modulation scheme and coding rate employed by the system.

In [5], ETSI BRAN defines a set of five indoor channel models (models A, B, C, D and E), to be used for HL/2 simulations (table 2).

Table 2. Parameters of channel models.

Name	Delay spread	Rice Factor	Environment
A	50 ns	-	office NLOS
B	100 ns	-	open space / office NLOS
C	150 ns	-	large open space NLOS
D	140 ns	10dB	large open space LOS
E	250 ns	-	large open space NLOS

A tapped delay line model where the average power declines exponentially with time has been chosen. All taps have Rayleigh fading statistics, except for the first tap of channel D which has a Ricean K factor of 10 and two factors, C_1, C_2 .

$$C_1 = \sqrt{\frac{K}{K+1}} \quad C_2 = \frac{1}{\sqrt{K+1}} \quad (1)$$

A classical Doppler spectrum corresponding to a terminal speed of 3 m/s is assumed for all taps.

3. Viterbi decoding: hard, soft quantified and soft no quantified

The Viterbi algorithm optimizes computational calculation. It is an efficient implementation of the Maximum-Likelihood (ML) detector. The algorithm searches the possible codewords of the convolutional code and detects the one that is most likely to have generated the received sequence [6]. The search procedure steps through the code trellis, and for each path through the trellis computes a metric which quantifies the variation between the received sequence and the possible coded sequence [7].

The 1/2-rate mother convolutional code used within the 5 GHz WLAN standards is described by a 64-state trellis and decoding is based on this trellis irrespective of the coding rate. Punctured bit, discarded at the transmitter, are replaced by dummy bits, inserted into the received bits stream. These dummy bits are marked so that they do not contribute to the calculation of the path metrics [8].

3.1. Hard Decision Decoding

With hard decision decoding, the Viterbi algorithm searches for the path through the trellis whose codeword differs in the least number of bits from the hard-limited received sequence.

3.2. Soft Decision no quantified Decoding

The Viterbi algorithm searches for the path through the code trellis that has maximum overall confidence. In this case the received symbols sequence will be demapped in a real values sequence.

3.3. Soft Decision quantified Decoding

The soft CSI decision results presented in the next section were based on simulations that used floating point accuracy within the path metric calculations. In practical receivers, the level of accuracy will be limited

to a small number. In this kind of decoder we use a 6-bit quantifier before the Viterbi decoder as recommends in [9].

4. Receiver and Transmitter diversity

As a way to improve radio link quality, a model of HL/2 receiver with N antenna diversity has been developed. Fig. 1 shows an example of a receiver with dual antenna diversity. Signals from both antennas, labelled as A and B, are demodulated, and the values of the k data subcarriers in an OFDM symbol $R_{A,k}$ and $R_{B,k}$ are introduced into the diversity combiner block. The combiner, according to a diversity algorithm, will merge the subcarrier values and the channel state information in order to form the signal R_k , which will pass through the channel equalizer and send to the inner receiver. We have been working with four different diversity algorithms: antenna selection, subcarrier selection, equal gain combining, and maximal ratio combining. It must be noted that PER measurements are done with a perfect knowledge of the channel, and with no frequency nor time offsets [10].

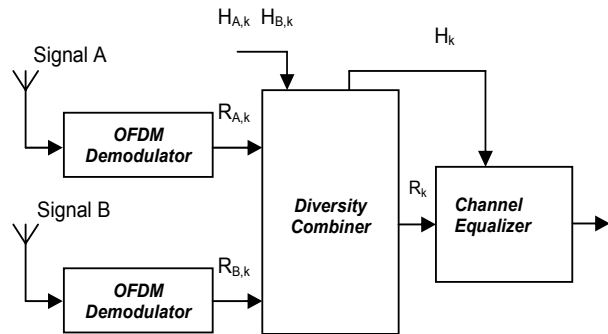


Fig. 1. Receiver with antenna diversity.

A. Antenna Selection Combining

For each symbol, the signal from the antenna with the highest average power is selected, that is, R_k is either $R_{A,k}$ or $R_{B,k}$ for all k depending on which signal is greater. To make a decision the sum of $|H_{A,k}|^2$ or the sum $|H_{B,k}|^2$ for all subcarriers is computed. After selection, the equalizer must compensate the channel response of the selected antenna for each OFDM symbol.

B. Subcarrier Selection Combining

The subcarrier with the highest magnitude response is selected, that is, the output R_k is either $R_{A,k}$ or $R_{B,k}$ for each k , depending on which is greater $|H_{A,k}|$ or $|H_{B,k}|$. In this case, for each subcarrier the equalizer compensates the values of the channel response at the subcarrier frequency of the selected entry.

C. Equal Gain Combining (EGC)

The subcarriers in both antennas are added, this can be done coherently (with phase aligning) or incoherently (without phase aligning). The output of the combiner is given in the first case by $R_k = R_{A,k} \left(e^{j \arg(H_{A,k})} \right)^* + R_{B,k} \left(e^{j \arg(H_{B,k})} \right)^*$ and in the second case by $R_k = R_{A,k} + R_{B,k}$. Therefore, the values to be compensated by the equalizer are given in the first case by the equation $|H_{A,k}| + |H_{B,k}|$, and in the second case by the equation $H_{A,k} + H_{B,k}$.

D. Maximal Ratio Combining (MRC)

The subcarriers in both antennas are phase aligned and weighted by their power. The output of the combiner is given by $R_k = R_{A,k}(H_{A,k})^* + R_{B,k}(H_{B,k})^*$. So, the values to be compensated by the equalizer are given by the equation $|H_{A,k}|^2 + |H_{B,k}|^2$, for all k .

Another way to improve radio link quality, a model of HL/2 transmitter with N antenna diversity has been developed. Fig. 2 shows an example of a transmitter with dual antenna diversity. As in the receiver diversity case, there are two signals streams.

These are modulated and transmitted separately. The values of the k data subcarriers in an OFDM symbol $T_{A,k}$ and $T_{B,k}$, are obtained from the diversity combiner block. The combiner, will merge the signal T_k and the channel state information in order to form the values of the k data subcarriers in an OFDM symbol $T_{A,k}$ and $T_{B,k}$, which will pass through the OFDM and Preamble and send to the antennas. We have been working with three different diversity algorithms: antenna selection, subcarrier selection and maximal ratio combining.

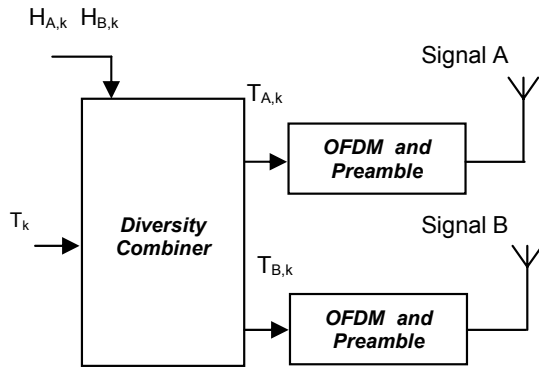


Fig. 2. Transmitter with antenna diversity.

A. Antenna Selection Combining

The antenna that transmits the highest average power is selected, that is, either $T_{A,k} = T_k$ and $T_{B,k} = 0$ for all k , or $T_{B,k} = T_k$ and $T_{A,k} = 0$ for all k dependent on which signal is greater. To make a decision the sum of $|H_{A,k}|^2$ or the sum $|H_{B,k}|^2$ for all subcarriers is computed.

B. Subcarrier Selection Combining

The subcarrier with the highest magnitude response is selected, that is, for any k , T_k is either $T_{A,k}$ or $T_{B,k}$, dependent on which is greater: $|H_{A,k}|$ or $|H_{B,k}|$.

C. Maximal Ratio Combining (MRC)

The subcarriers are rotated so that they are aligned at the receiver and weighted by their power and they are transmitted on each antenna: $T_{A,k} = T_k(H_{A,k})^* / (|H_{A,k}|\sqrt{2})$ and $T_{B,k} = T_k(H_{B,k})^* / (|H_{B,k}|\sqrt{2})$ for all k .

5. Results

The tables below show the gains respect no diversity technique when a channel type A (Rayleigh Distribution) and a channel type D (Rice Distribution) is used in a transmission mode number 6 and when subcarrier selection (SubS), antenna selection (AntS),

maximal ratio combining (MRC) and equal gain combining (EGC) are used.

Channel and method	Receiver diversity		Transmitter diversity	
	Two antennas	Three antennas	Two antennas	Three antennas
A - AntS	1 dB	2 dB	0 dB	0.5 dB
A - SubS	9 dB	10 dB	8 dB	9 dB
A - MRC	10 dB	11.5 dB	8 dB	9.5 dB
A - EGC	10 dB	11.5 dB	-	-
D - AntS	0 dB	0.5 dB	0 dB	0 dB
D - SubS	3 dB	4 dB	2.5 dB	3 dB
D - MRC	6 dB	8 dB	4.5 dB	5 dB
D - EGC	5 dB	7 dB	-	-

Table 3. Comparison between receiver and transmitter diversity using hard decision.

Although MRC has a better performance than subcarrier selection, the latter has a lower complexity. The method with lowest complexity is antenna selection since it does not need to demodulate all the signals as in MRC and subcarrier selection [11].

In transmitter diversity simulations we have discarded equal gain combining method because it has a similar implementation cost than MRC and lower performance.

A. Hard Decision

Receiver and Transmitter with two or three antenna diversity using Rayleigh and Rice distribution: In table 3 can be compared the gains respect no diversity technique.

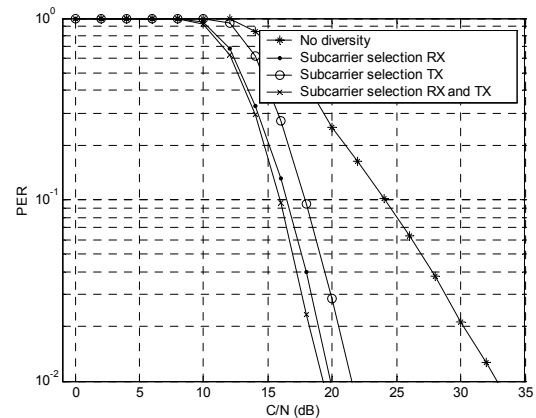


Fig. 3. Results of using two antennas at transmitter and receiver and a radio channel with Rayleigh distribution.

Transmitter with two antenna diversity and receiver with two antenna diversity: Fig. 3 shows the PER when a channel A is used in a transmission mode number 6 and when no diversity technique and the diversity techniques in both transceivers are used. That figure shows that antenna selection in receiver and transmitter improves the performance in 1 dB compared with subcarrier selection in reception and 4 dB compared with subcarrier selection in transmission.

B. Soft Decision no quantified

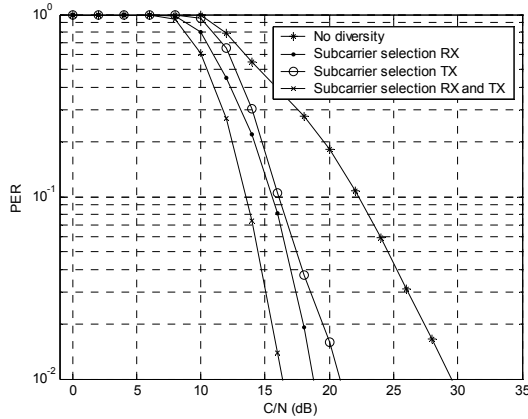


Fig. 4. Results of using two antennas at transmitter and receiver and a radio channel with Rayleigh distribution.

Receiver and Transmitter with two or three antenna diversity using Rayleigh and Rice distribution: In table 4 can be compared the gains respect no diversity technique.

Channel and method	Receiver diversity		Transmitter diversity	
	Two antennas	Three antennas	Two antennas	Three antennas
A - AntS	2 dB	3 dB	1.5 dB	2.5 dB
A - SubS	10 dB	12.5 dB	10 dB	11 dB
A - MRC	11 dB	15 dB	9 dB	13 dB
A - EGC	11 dB	14.5 dB	-	-
D - AntS	0.5 dB	1 dB	0 dB	0 dB
D - SubS	5 dB	5.5 dB	4.5 dB	5 dB
D - MRC	6.5 dB	9 dB	4.5 dB	7.5 dB
D - EGC	5.5 dB	7.5 dB		

Table 4. Comparison between receiver and transmitter diversity using soft no quantified decision.

Transmitter with two antenna diversity and receiver with two antenna diversity: Fig. 4 shows the PER when a channel A is used with a transmission mode number 6 and when no diversity technique and the diversity techniques in both transceivers are used. That figure shows that antenna selection in receiver and transmitter improves the performance in 1 dB compared with subcarrier selection in reception and 4 dB compared with subcarrier selection in transmission.

C. Soft Decision quantified

Receiver and Transmitter with two or three antenna diversity using Rayleigh and Rice distribution: In table 5 can be compared the gains respect no diversity technique.

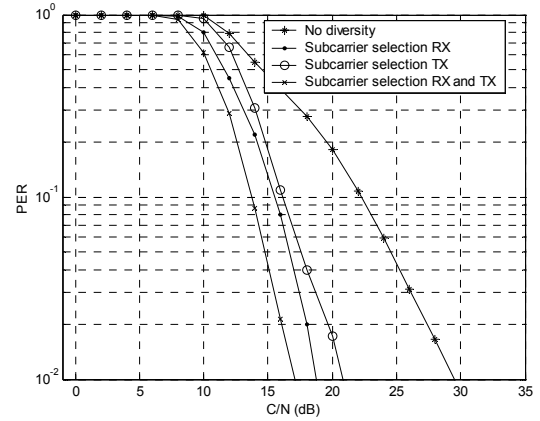


Fig. 5. Results of using two antennas at transmitter and receiver and a radio channel with Rayleigh distribution.

Channel and method	Receiver diversity		Transmitter diversity	
	Two antennas	Three antennas	Two antennas	Three antennas
A - AntS	2 dB	3 dB	1.5 dB	2.5 dB
A - SubS	10 dB	12 dB	10 dB	11.5 dB
A - MRC	11 dB	15 dB	8.5 dB	14 dB
A - EGC	11 dB	14.5 dB	-	-
D - AntS	0.5 dB	1 dB	0 dB	0 dB
D - SubS	5 dB	5.5 dB	4 dB	5 dB
D - MRC	6 dB	8.5 dB	4.5 dB	7.5 dB
D - EGC	5.5 dB	7.5 dB		

Table 5. Comparison between receiver and transmitter diversity using soft quantified decision.

Transmitter with two antenna diversity and receiver with two antenna diversity: Fig. 5 shows the PER when a channel A is used with a transmission mode number 6 and when no diversity technique and the diversity techniques in both transceivers are used. That figure shows that antenna selection in receiver and transmitter improves the performance in 1 dB compared with subcarrier selection in reception and 3.5 dB compared with subcarrier selection in transmission.

D. Comparison between Viterbi Decoding Strategies

We have obtained, using a channel A in a transmission mode number 6 a comparison between hard, soft no quantified and soft quantified with no diversity, receiver diversity, transmitter diversity and receiver and transmitter diversity simultaneously.

With no diversity, SDU offers the best results, with a gain of 1 and 5 dB respect SDQ and HD, respectively. In the case of transmitter and receiver diversity, we compare the subcarrier selection method obtaining an insignificant improvement of SDU respect the others, only 0.5-1 dB between SDU and SDQ, and more stressed between SDU and HD.

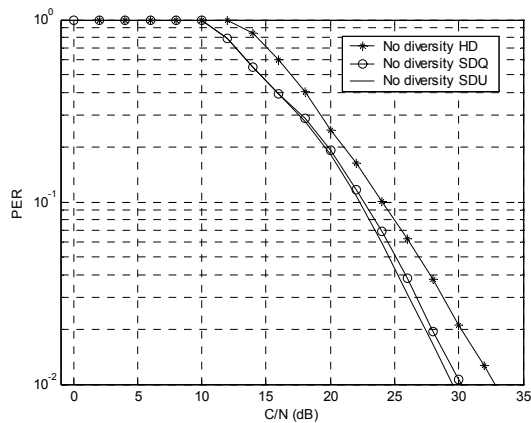


Fig. 6. Comparison between hard, soft quantified and soft no quantified without diversity.

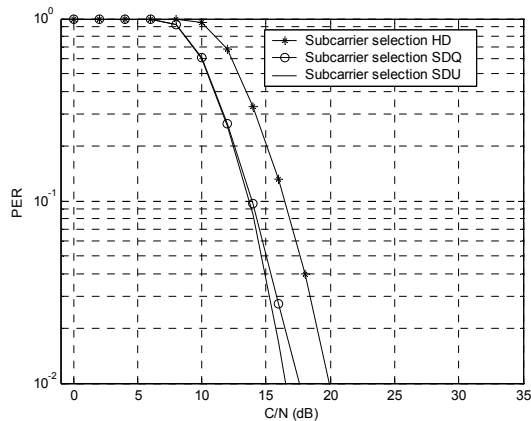


Fig. 7. Comparison with receiver diversity using subcarrier selection.

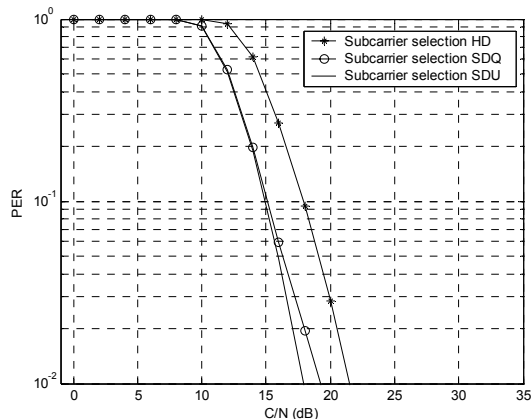


Fig. 8. Comparison with transmitter diversity using subcarrier selection.

6. Conclusions

This work has presented the use of multiples antennas in a Hiperlan/2 receiver or transmitter using Viterbi decoding. By means of simulation we have evaluated different diversity techniques: antenna selection, subcarrier selection, equal gain combining and maximal ratio combining and analysed different Viterbi decoding strategies: hard, soft quantified and soft no quantified.

As a summary referred to the diversity techniques, same system performance can be achieved by applying the diversity techniques either at the transmitter or receiver side. If the diversity techniques are always

applied at the Access Point, the average cost and weight of the Mobile Terminal can be reduced by sharing all the processing at the common Access Point.

In the comparison between Viterbi decoding strategies we can see that with no diversity, SDU offers the best results, with a gain of 1 and 5 dB respects SDQ and HD, respectively. In the case of transmitter and receiver diversity, we compare the subcarrier selection method obtaining an insignificant improvement of SDU respect the others, only 0.5-1 dB between SDU and SDQ, and more stressed between SDU and HD.

REFERENCES

- [1] ETSI TS 101 475 v1.2.2 BRAN; HIPERLAN Type 2; Physical (PHY) layer.
- [2] J. Medbo and P. Schramm, "Channel Models for HIPERLAN 2" ETSI BRAN document 3ERI085B, 1998.
- [3] M.R.G. Butler, et al. "The performance of HIPERLAN/2 Systems with multiple antennas". Proceedings of IEEE Vehicular Technology Conference, Rhodes, 2001.
- [4] J. H. Winters, J. Salz, and R. D. Gitlin, "The impact of antenna on the capacity of wireless communication systems" IEEE Trans. Comm., vol. 42, pp.1740-1751, 1994.
- [5] BRAN WG3 PHY Subgroup. Criteria for Comparison. ETSI/BRAN document no. 30701F, 1998.
- [6] A. Viterbi, "Convolutional Codes and Their Performance in Communication Systems" IEEE Transactions on Communications, vol. 19, no. 5, pp. 751-772, 1971.
- [7] G. Forney, "The Viterbi algorithm" Proceedings of the IEEE, vol. 61, no. 3, pp. 268-278, 1973.
- [8] W. Lee, H. Park, and Park J., "Viterbi decoding method using channel state information in COFDM system" IEEE Trans. on Consumer Electronics, vol. 45, no. 3, pp. 533-537, 1999.
- [9] M.R.G. Butler, et al. "Viterbi Decoding Strategies for 5 GHz Wireless LAN Systems" Vehicular Technology Conference, 2001. VTC 2001 Fall. IEEE VTS 54th, Volume: 1, 2001 Page(s): 77 -81 vol.1
- [10] J.D. Moreira, et al. "Diversity techniques for OFDM based WLAN Systems". Proceedings of IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), pp. 1008-1011, Lisbon, 2002.
- [11] P. Corral, et al. "Diversity techniques for OFDM based WLAN systems in Rice and Rayleigh Channels" Proceedings of Sixth Baiona Workshop on Signal Processing in Communications, pp. 25-31, Baiona (Spain), 2003.