Physical Layer Performance of HIPERLAN/2 in Measured Indoor Channels

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Abstract— **In this paper, the performance of physical layer (PHY) of HIPERLAN/2 is evaluated in terms of long transport channel packet data unit (LCH-PDU) error rate (PER) and throughput in a noise-limited scenario. The evaluation has been addressed in a typical indoor environment using measured indoor channels carried out by a joint UFC-ERICSSON research team at ERICSSON research building in Kista, Sweden.**

Keywords— **HIPERLAN/2, OFDM and link adaptation.**

I. Introduction

Two very known wireless local-area network (WLAN) standards are HIPERLAN/2 (high performance radio LAN Type 2) and IEEE 802.11a defined respectively by ETSI BRAN [1] and IEEE [2], [3]. The HIPERLAN/2 was conceived in the unlicensed 5GHz band and provides data rates of 6Mbps up to 54Mbps through link adaptation modes in order to support broadband multimedia services.

HIPERLAN/2 is based on cellular network topology combined with *ad hoc* networking capabilities. Two operation modes is used: centralized mode (CM) and direct mode (DM). The direct mode enable *ad hoc* capabilities. The centralized operation mode applies to the cellular networking topology where each cell is controlled by an access point (AP) that covers a certain geographical area. In this mode, the communication between two mobile terminals is controlled mandatorily by the access point. This mode of operation is mainly indicated to locals where the coverage area is larger than a cell. The directed mode applies to *ad hoc* networking topology where the coverage area is limited by one radio cell only. In this mode, mobile terminals can exchange data directly with another without the necessity of the access point controls this communication. The function of the access point in this case is limited to radio resource management (RRM) functions.

In the PHY the HIPERLAN/2 is based on orthogonal frequency division multiplexing (OFDM) and link adaptation. The first technique is attractive due to capacity to deal with frequency-selective fading while link adaptation enables the system to dynamically trade-off link reliability and data rate according to the quality of the available radio link. This trade-off is achieved through the different transmission modes. In HIPERLAN/2 seven modes are defined from which, six modes are mandatory and one mode is optional.

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This paper is focused on performance evaluation of HIPERLAN/2 in a typical indoor multipath channel with three different polarization. The indoor multipath measurement campaign was carried out by a joint UFC-Ericsson research team at the Ericsson Research building in Kista, Sweden. A physical layer simulator of HIPERLAN/2 was conceived in accordance with the standard defined by ETSI in [1], and this simulator uses the information of the measured indoor channels in three different antenna orientations for the evaluation of polarization effects.

This paper is organized as follows. In Section II the physical layer of the HIPERLAN/2 is described. Section III describes the link level simulator conception. Section IV describes the channel measurements procedure. Finally, Section V summarizes the results and Section VI concludes the paper.

II. HIPERLAN/2 PHY

The PHY of HIPERLAN/2 is based on TDMA/TDD multiple access. In the Fig. 1 is shown the mapping of higher-layers data units down physical bursts. The data-link-control (DLC) layer is composed of long transport channels packet data unit (LCH-PDU) for data user transmission and short transport channel (SCH) for messages control. This layer consists of a radio link control (RLC) sublayer, an error control (EC) protocol, and a medium access control (MAC) protocol.

The transmission format on physical layer is a burst of variable length, which consists of a preamble and a data part. The data field is composed of a train of SCH and LCH PDUs that are ready to be transmitted or received by a mobile terminal. The LCH-PDU are shown in more details in Fig. 2, with packet size equals 54 bytes, where the payload is 49.5 bytes and the remaining 4.5 bytes are used for the PDU type (2 bits), sequence number (10 bits, SN) and cyclic redundancy check (CRC-24).

On the HIPERLAN/2 a multi-rate physical layer is applied in order to improve the radio link quality for different channel conditions, where the appropriate mode is selected by a link quality scheme. The data rates range of 6Mbps up to 54Mbps is achieved varying the modulation scheme and the puncturing pattern of the mother convolutional code. As modulation schemes, BPSK, QPSK and 16QAM are used as mandatory formats, whereas 64QAM is applied as an optional format. The modes defined for HIPERLAN/2 are shown in Table I.

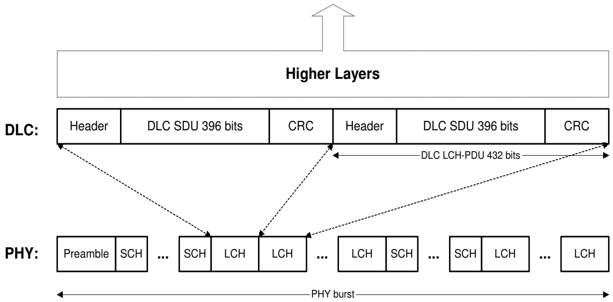


Fig. 1. Mapping of higher layer packets onto the physical layer of HIPERLAN2.

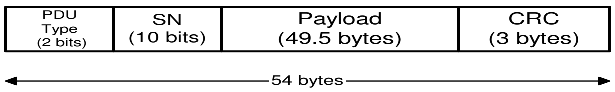


Fig. 2. LCH-PDU format (one-sector antenna).

The HIPERLAN/2 is based on the orthogonal frequency division multiplexing (OFDM) modulation scheme due to its good performance in selective fading channels, mainly when adaptive power and subcarrier allocation is employed [4]. The specification says that each symbol is composed by a group of 52 subcarriers, where 48 subcarriers are used to data and 4 are pilot to channel estimation. Two parts compose the symbol interval: a useful symbol part duration and a cyclic prefix to maintain the orthogonality among the multiples subcarries avoiding the intercarrier interference (ICI) effect. The cyclic prefix consists of a cyclic continuation of the useful part and it is insert before it. The length of the useful symbol part is equal to 64 samples and its duration is $32\mu s$. For cyclic prefix length there are two possible values in the HIPERLAN/2 systems: $800ns$ and optional $400ns$. Numerical values of OFDM parameters are given in Table II.

III. HIPERLAN/2 Simulator

The physical layer simulator of HIPERLAN/2 was based on specification that can be found in [1]. It is simulated using Monte Carlo approach including: channel encoder, puncturing, interleaving, burst mapping modulator, OFDM modulator, pulse shaping, measured channel modelling, OFDM demodulator, de-interleaving and decoder. The Fig. 3 shows the block diagram of simulator [5], [6].

TABLE I
Modes parameters defined for HIPERLAN/2.

Mode	Modulation	Coding Rate	Nominal Bit Rate R_{mode} [Mbps]
1	BPSK	1/2	6
2	BPSK	3/4	9
3	QPSK	1/2	12
4	QPSK	3/4	18
5	16QAM	9/16	27
6	16QAM	3/4	36
7	64QAM	3/4	54

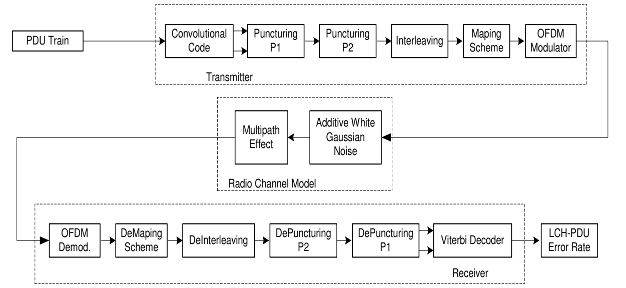


Fig. 3. Simulator structure of HIPERLAN/2.

TABLE II
OFDM Parameters.

Parameters	Value
Sampling rate $f_s = 1/T$	20 MHz
Useful symbol part duration T_U	$64 \cdot T = 32\mu s$
Symbol interval T_S	$80 \cdot T = 4\mu s(T_U + T_{CP})$
Number of data sub-carries N_{SD}	48
Number of pilot sub-carries N_{SP}	4
Total number of data sub-carries N_{ST}	$52(N_{SD} + N_{SP})$
Sub-carries spacing Δ_f	0.3125 MHz $(1/T_U)$

The simulator consider a noise-limited scenario. For this scenario, 2000 LCH-PDU packets are generated and transmitted. The main output of simulator is: LCH-PDU error rate (PER) vs. signal to noise ratio (SNR). For PER consideration, a packet is assumed be erroneous, if coding redundancy check (CRC) fails for each LCH-PDU packet.

Based on PER values, the throughput can be obtained by relation:

$$\text{Throughput} = (1 - PER) \cdot R_{mode} \qquad (1)$$

where R_{mode} is the nominal bit rate in Mbps for each transmission mode, see Table I.

IV. Channel Measurements

The channel taps are taken from the measured wireless indoor channels using a multiple-input multiple-output (MIMO) approach, which requires multiple antennas at base station and mobile terminal, bringing the possibility of spatially multiplexing several data streams, thus increasing the capacity linearly with the number of independent data streams over certain conditions [5], [7], [8]. A network analyzer (NWA) was used to sample the channel at 201 equidistant frequencies (separated by 1MHz) between 5,15 and 5,35GHz (200MHz bandwidth). A personal computer (PC) was used for data acquisition and instrument control. Due to its simplicity and versatility, a synthetic array technique was employed at both transmitter and receiver [6]. At the transmitter, a 3D robot was used to sample the channel in the three-dimensional space. At the receiver, a linear positioning unit (LPU) with stepping motor was employed in *x* and *y*, with 11 receive positions in each axis. In each measurement run the MIMO channel is measured by sampling 33 (*x*, *y* and *z*) spatial positions at the transmitter and 22 (*x* and *y*) at the receiver, giving a total of 145926 (33 x 22 x 201) elements. The step length was 2cm

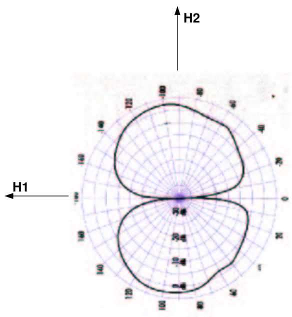


Fig. 4. Elevation antenna pattern.

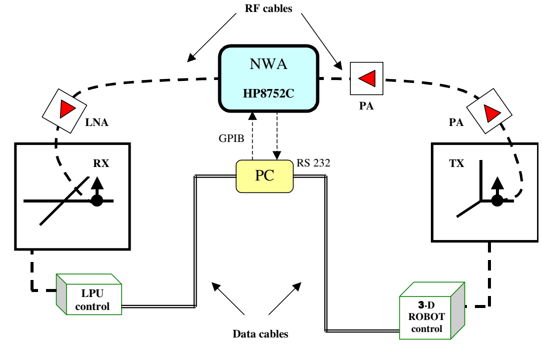


Fig. 5. Schematic drawing of the measurement system.

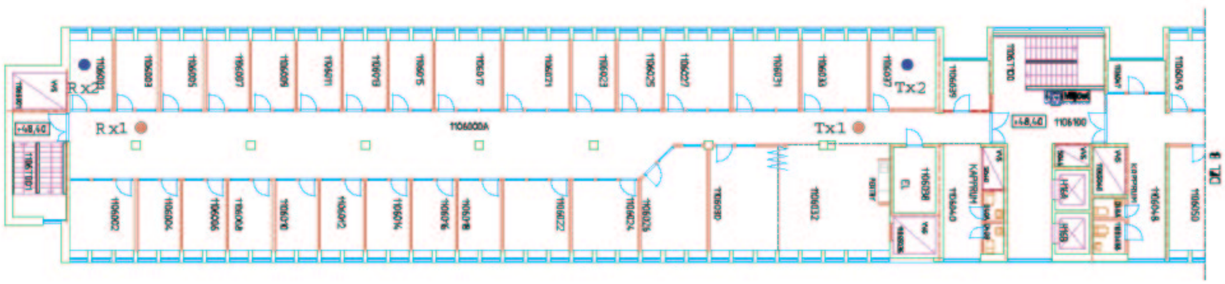


Fig. 6. Floorplan geometry and measurement locations.

TABLE III
SUMMARY SCENARIOS.

Transmitter Position Tx(3D robot)	Receiver Position Rx(LPU)	Scenario
1	1	corridor-to-corridor [cc]
1	2	corridor-to-room [cr]
2	2	room-to-room [rr]

in x, y and z. The schematic drawing of the measurement system is shown in Fig. 5. The measurement campaigns were performed at the top floor of a 12,5m wide, 115m long and 6 storeys high office building of Ericsson Radio Systems in Kista, Sweden, see Figs. 6 and 4. The inner walls, between each room, are made of double plasterboard supported by vertical metal studs. Along the corridor, the inner walls are made of glass supported by wooden studs. The floor and pillars in the corridor as well as in the outer wall are made of reinforced concrete. The office doors are made of fibreboard and in most of the walls between each room there are a metal whiteboard in connection to the corridor.

For each measurements campaign/scenario, the normalized average power delay profile was obtained by averaging over the profiles of all transmit and receive elements and all antenna orientations. The average received power was -17dB in the corridor-to-corrido scenario, -25dB in the room-to-corridor scenario and -59dB in the room-to-room scenario.

In the corridor-to-corridor measurement Fig. 7, the peaks in the PDP indicate the presence of three main clusters of delay. Each cluster groups 4 to 5 peaks. The first peak appears around 0.14s, which is equivalent to a distance of 42m. By simple ray tracing, we concluded that the first peak corresponds to a reflection path in the door at the end of the corridor (see Fig. 6). We attribute the other peaks in the first cluster to reflections in the two doors of the adjacent corridor. It was observed that the separation between two adjacent peaks is around 40ns (12m distance). The second and third clusters of delays are just a consequence of the multiple reflections, back and forth at the ends of the corridor.

In the corridor-to-room measurement, three main delayed peaks can be seen in Fig. 8. Since there is no line-of-site in this scenario, the received signal corresponds to multiple scattered and diffracted paths inside the room, where the transmitter is located.

In the case of the room-to-room scenario, a strong peak can be observed at 0.4s, corresponding to a total distance of 120m. This peak is the result of a specular reflection in the outside wall of a neighboring building. This strong path indicates that considerable amount of power of the transmitted signal reached the receiver from outside the corridor.

Office environments are regarded as typical environments for wireless local area networks (WLAN) and BLUETOOTH, which are compelling applications for MIMO systems. The 5,2GHz band was selected for the purpose of this work, since it has been assigned for WLANs, e.g. HIPERLAN and IEEE 802.11a [1]–[3].

The measurement campaigns were conducted in three scenarios. In the first scenario, both the transmitter and receiver

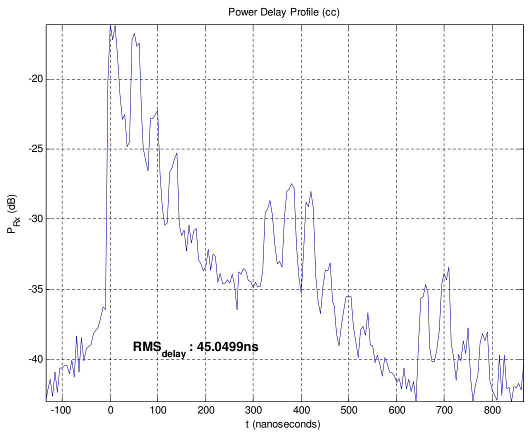


Fig. 7. Power-delay profile for corridor-to-corridor measurement.

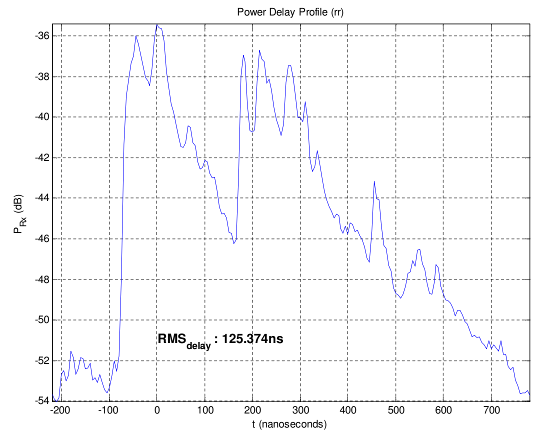


Fig. 9. Power-delay profile for room-to-room measurement.

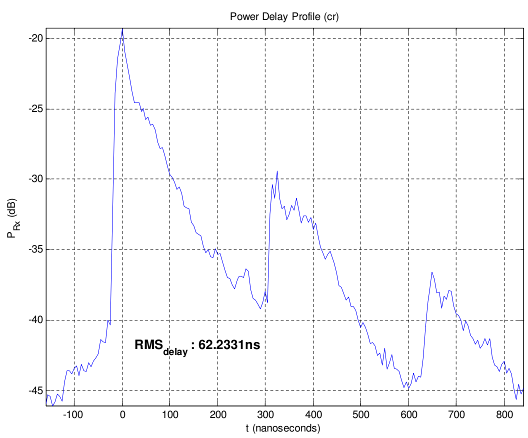
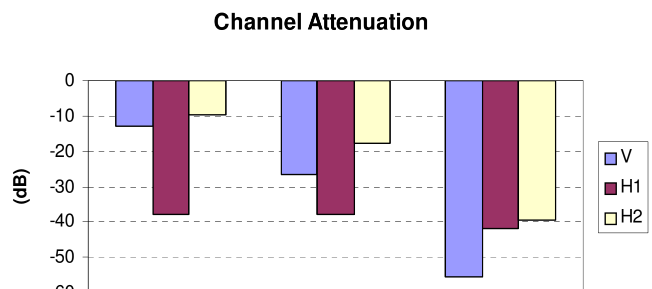


Fig. 8. Power-delay profile for corridor-to-room measurement.



	cc	cr	rr
V	-12,6866	-26,5712	-55,6797
H1	-37,7018	-37,8729	-41,8446
H2	-9,5547	-17,8402	-39,5088

Fig. 10. Channel Attenuation.

were placed in opposite ends of the corridor (Tx 1 and Rx 1, LOS [cc]). In the second scenario, the transmitter was kept in one end of the corridor while the receiver was moved to inside the room (Tx 1 and Rx 2, NLOS [cr]). In the third scenario both the transmitter and receiver were placed in different rooms, one at each end of the corridor (Tx 2 and Rx 2, NLOS [rr]). In order to allow for the evaluation of antenna polarization effects, we considered 3 different antenna orientations at both the transmitter and receiver. We now establish the basic conventions and notations used to define the measurement campaigns as well as the considered antenna orientations.

Antenna orientations:

1) Vertically mounted (V),
2) Horizontally mounted, along the corridor (H1),
3) Horizontally mounted, perpendicular to the corridor (H2).

V. RESULTS

The physical layer performance of the HIPERLAN/2 is shown in this section using Monte Carlo simulations in a noise-limited scenario considering the transmission modes 1, 3, 5 and 7. The channel profile multipath was obtained by measured indoor carried out by a joint UFC-Ericsson research team at the Ericsson Research building in Kista, Sweden. For all transmission modes 2000 LCH-PDU packets were transmitted in the physical layer.

At shown in Figs. 11, 13 and 15 the PDU error rate (PER) curves vs. received SNR while Figs. 12, 14 and 16 shown plots of throughput vs. received SNR where the mapping to throughput values was obtained through the equation (1). From these figures we can observe that the modes definition (link adaptation) is efficient in provide the best transmit parameters combination in accordance with the momentary link quality, e.g. SNR or SINR. Therefore, the idea of the link adaptation is that the user be able to adapt some transmission parameters like modulation and/or coding rate in conformity with the channel variations.

Considering now the simulation scenarios, from the Figs. 11 up to 16 we can observe that for the same scenario, for example the scenario corridor-to-corridor, the effect of the antenna orientation has a little impact on the results. This can be explained by observing that all three different polarization experiment similar delay spread.

The consideration of the same received SNR for the different antenna orientation is not a correct hypothesis due to the antenna pattern and/or the propagation environment just to mention some. In fact, we observed from the channel measurement campaign that the channel attenuation will be dependent on the scenario and on polarization domain considered. Therefore, in the Fig. 10 it is shown the attenuation for each scenario and polarization domain. In the matrix the rows represent the polarization domains while the columns represent the considered scenario. With this observation, we can now conclude about the influence of the antenna orientation. For example, considering the scenario [cr] the best polarization choice it would be H2 that achieves the less attenuation (-18dB in this case) considering the transmit power normalized to 0dB. Therefore, since SNR differences between (H2 and V) and (H2 and H1) are about 9 and 19dB respectively it would be necessary to increase the transmit power by these amount to achieve the same PER level. For example, in Fig. 13, the PER curves for V and H1 should be shifted into the right side by 9 and 19dB, respectively.

VI. Conclusions and Perspectives

This work has presented the performance evaluation in a HIPERLAN/2 physical layer in measured indoor channel when different antenna orientation (polarization) is considered. By simulation we have concluded that the modes definition is efficient to provide high data rates in accordance with the link quality. And the use of polarization can be a new domain to be exploited representing a improvement in the capacity. A important reason for the consideration of polarization diversity is that these schemes are attractive to consideration in mobile terminals due to space limitations.

In recent years, a large number of papers has been published on multiple-input multiple-output (MIMO) systems. It is shown that a huge increasing in the capacity can be achieved considering a link level point of view. A better capacity benefit can be reached with hybrid space-polarization diversity in MIMO systems. With this approach the range of the PER variation among the different scenarios is reduced. This means that more stable capacity and quality of service (QoS) can be achieved when hybrid space-polarization diversity is employed (e.g. using antenna arrays with dual polarized elements).

Our approach in this work considered only a single-input single-output (SISO) link. In fact, the use of MIMO system can improve the system's capacity using the different polarization schemes. A future upgraded of this work is the implementation of MIMO transmit technique over the HIPERLAN/2 in order to make possible to evaluate potential gains that this technique can offer.

Acknowledgements

The authors would like to express their thanks to Jonas Medbo from ERICSSON RESEARCH, Kista, Sweden, for providing the measurement data.

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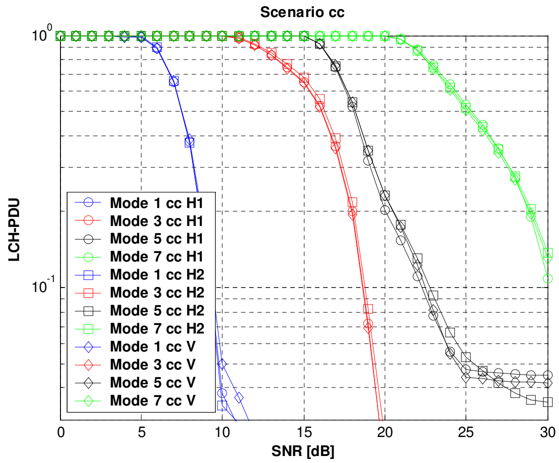

Fig. 11. LCH-PDU performance for HIPERLAN/2 in a scenario corridor-to-corridor.

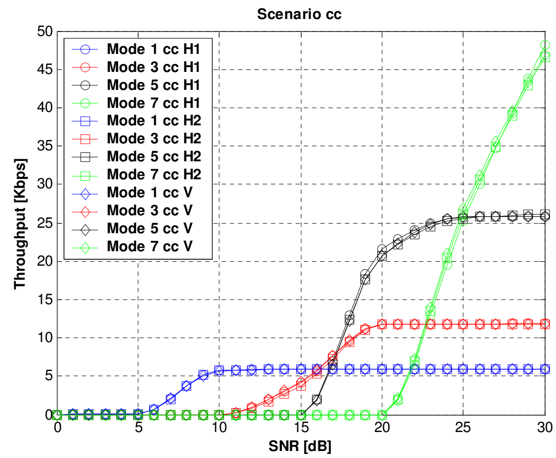

Fig. 12. Throughput performance for HIPERLAN/2 in a scenario corridor-to-corridor.

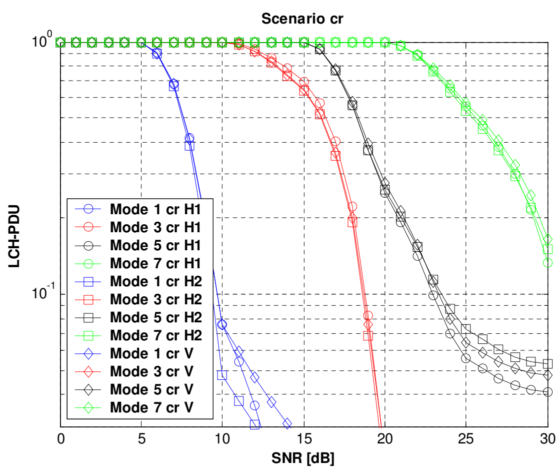

Fig. 13. LCH-PDU performance for HIPERLAN/2 in a scenario corridor-to-room.

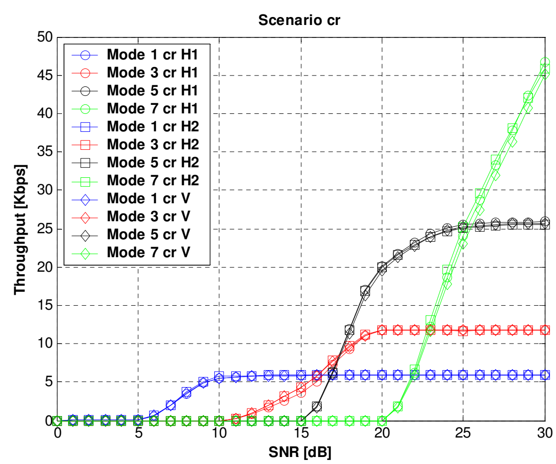

Fig. 14. Throughput performance for HIPERLAN/2 in a scenario corridor-to-room.

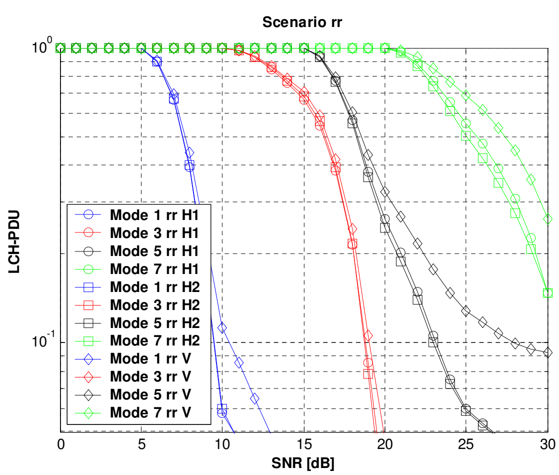

Fig. 15. LCH-PDU performance for HIPERLAN/2 in a scenario room-to-room.

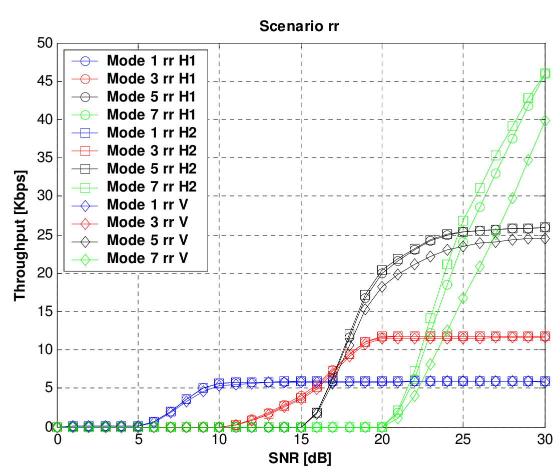

Fig. 16. Throughput performance for HIPERLAN/2 in a scenario room-to-room.