Simulation Analysis of Wireless Channel Effect on IEEE 802.11n Physical Layer

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***Abstract*—IEEE 802.11n standard came as a rescue; the existing standards are increasingly seen as inadequate since applications become more complex and require more bandwidth. Several techniques have been put into operation to meet two basic requirements: significantly greater bit rate and radio coverage. However, studies have shown that the theoretical limit in terms of throughput is far from being reached and that the received power does not explain the performance degradation. A list of suspect parameters is analyzed in this paper to assess their effect on performance of the IEEE 802.11n physical layer taken as an application of MIMO technology in indoor context. It is shown that even if the received power is high, the data rates for a 2x2 MIMO 802.11n can vary between 117 Mbps and 130 Mbps depending on the angular spread values. The antenna spacing can compensate the performance degradation caused by other parameters. Results are given in terms of correlation coefficient, other channel characteristics and the packet error rate.**

Keywords-MIMO; IEEE802.11n; WLAN; Packet Error Rate (PER); channel models

I. INTRODUCTION

The originality of the standard IEEE802.11n is based on Multiple-Input Multiple-Output (MIMO) technology which is recognized as a good solution in the development of broadband Wireless Local Area Networks (WLAN). This technique is essential for digital communications to increase data rates and/or to improve system performance. Other important enhancements concern transmission channels operating with 40 MHz bandwidth and frame aggregation mechanisms to have a better MAC efficiency. This transmission system, which can reach in principle a throughput of 100 to 300 Mbps, is likely to extend a wired Ethernet protocol over a WLAN to provide interactive multimedia services to mobile users.

However, because of the large number of parameters that may be involved, system performance is variable, and can be far from the theoretical performance promised.

In all WLAN, the major difficulties come from the availability of frequencies, the nature of the propagation environment (indoor, outdoor, building materials, etc), and the equipment used. New difficulties are met in 802.11n networks, due to the large number of parameter combinations that can arise i.e. for each link, two transmitters and two receivers operate in parallel within the same MIMO channel and the number of data streams transmitted at each time, increases. The term "MxN" is used to describe the number of antennas at each end of the transmission channel 802.11n. The minimum required by the standard is the so-called "2x2" (two transmitting antennas and two receiving antennas). Previous studies have proved the impact of the channel correlation properties on the packet error rate (PER) [1].

Therefore, in Section II, a description of the wireless channel model is given and an identification of the different parameters involved in the quality of an IEEE 802.11n link is made. Then, an analysis of the effect of the various elements related to the propagation on the performance in terms of bit rate is presented in Section III. Section IV presents the impact of a couple of parameters on the PER assessed in order to identify relevant areas corresponding to a low packet error rate. The conclusion is drawn in Section V.

II. SIMULATIONS DESCRIPTIONS AND CHANNEL MODEL

A. Simulations Set Up

Matlab and Simulink were used in order to simulate 802.11n links. The transmission chain implements the new technologies of the IEEE 802.11n physical layer [2]. The most important functionalities of the simulation blocks are:

- A 2x2 MIMO system
- A set of Modulation and Coding Schemes (MCS): only the $MCS_{8...15}$ could be used for two spatial streams. The BPSK, QPSK, QAM-16, QAM-64 modulations are used with the coding rates (1/2, 3/4, 2/3, 5/6)
- OFDM (only 20 MHz supported): 52 sub-carriers (data), 64 FFT points, with use of cyclic prefix
- MIMO Detection: a MMSE linear detector
- Antenna spacing for Tx and Rx arrays is $\lambda/2$ by default, where λ is the wavelength
- Omni vertically polarized antennas
- Support for TGn channel models which will be described in the next paragraph.

B. Description of the Channel Model

The propagation channel model used for the simulations is designed by the "High Throughput Task Group" (TGn). The Matlab script is described in [2]. Accurate explanations of the channel modeling can be found in [3] and [4].

The propagation channel imposes delay and phase shifts on the signals exchanged between the transmitter and the receiver. The received signals arrive in clusters, and each one is composed of several rays. The standard defines several channel models (A to F) in order to model multiple propagation environments.

The use of A-F models has been presented in [5]. These models are representative for small environments, such as residential homes and small offices, i.e. indoor environments. Model F represents larger indoor or outdoor propagation environments. Each model has its own parameters such as tap delays, corresponding power, Azimuth Spread (AS) and Angle of Arrival/Departure (AOA/AOD). In order to analyze a rich environment and assess the impact of more parameters, the choice was made on the model D which represents typical offices. The MIMO channel matrix H for each tap, at one instant of time in the power delay profile models can be separated into a constant (LOS) matrix and a variable Rayleigh matrix.

For a 2 x 2 MIMO system, the channel matrix H [4] is expressed as

$$H = \sqrt{P}\left(\sqrt{\frac{K}{K+1}}H_F + \sqrt{\frac{1}{K+1}}H_V\right) =$$

$$\sqrt{P}\left(\sqrt{\frac{K}{K+1}}\begin{bmatrix} e^{j\varphi_{11}} & \frac{e^{j\varphi_{12}}}{\sqrt{10}} \\ \frac{e^{j\varphi_{21}}}{\sqrt{10}} & e^{j\varphi_{22}} \end{bmatrix} + \sqrt{\frac{1}{K+1}}\begin{bmatrix} X_{11} & \frac{X_{12}}{\sqrt{2}} \\ \frac{X_{21}}{\sqrt{2}} & X_{22} \end{bmatrix}\right) \quad (1)$$

Where X_{NM} (N-th receiving and M-th transmitting antenna) are correlated zero-mean, unit variance, complex Gaussian random variables as coefficients of the variable (Rayleigh) matrix H_V, $e^{j\varphi_{NM}}$ are the elements of the constant matrix H_F, K is the Rician factor, and P is the power of each tap.

To correlate the X_{NM} elements of the matrix X [5], the Kronecker product of the transmit and receive correlation matrices is preformed :

$$\{[R_{Tx}] * [R_{Rx}]\}^{\frac{1}{2}}[H_{iid}] \quad (2)$$

where R_{Tx} and R_{Rx} are the transmit and receive correlation matrices respectively, and H_{iid} is a vector (only here, otherwise it is a matrix) of independent, complex Gaussian random variables with zero mean and unit variance.

R_{Tx} and R_{Rx} matrices are derived based on the Power Angular Spectrum (PAS) formulation [4-5]. This model supposes that there is no correlation between transmitting and receiving antennas. The PAS for each tap is a function of the antenna spacing, angular spread (AS) and angle of incidence, angle of arrival (AOA) or angle of departure (AOD), depending on Tx or Rx of each cluster.

Some angular elements are shown in Fig. 1 for a 3x3MIMO system.

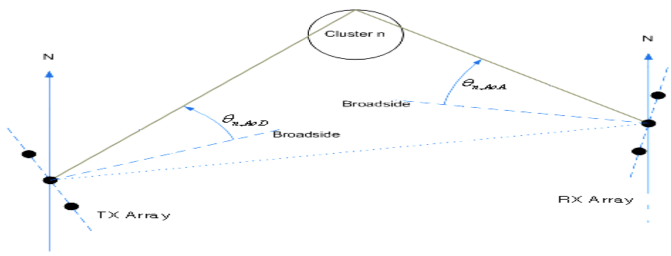

Figure 1. AOD/AOA parameters

In Fig. 2, the results of a comparative analysis of four reference channels are shown, using the simulation environment described above. Curves represent the evolution of packet error rate (PER) versus signal to noise ratio (SNR), for a simple additive white Gaussian noise (AWGN) channel. SNR values are high enough to achieve an acceptable level PER. The modulation and coding scheme used is MCS 15.

By comparing both TGN-B channels (indoor residential with two clusters) and TGN-D (large offices with three clusters), we conclude that the 802.11n MIMO system takes advantage of the richness of the environment since the model D is less demanding in terms of SNR than the model B. This can be explained by the proper use of multi-path made by a MIMO system when their delays are below the limit of the guard interval.

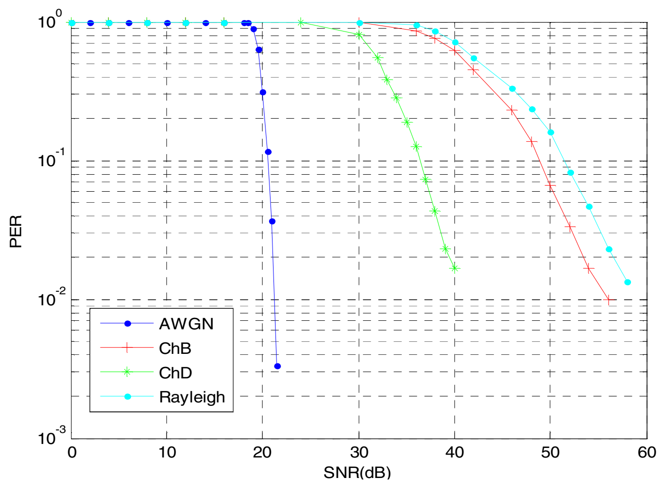

Figure 2. Simulated PER versus SNR for reference channels.

III. ANGULAR AND PARAMETERS MCS

A. *Bit Rate Adaptation*

The IEEE 802.11n systems use the 20 or 40 MHz bandwidth within 15 different MCS numbered 1 to 15, MCS8 to 15 corresponding to the use of 2 spatial streams. Depending on the indoor transmission environment, the system switches from one MCS to another, in order to adapt the bit rate to the link quality imposed by the radio environment (obstacles between the transmitter and receiver, received power and interference level). The PER is one of the criteria used in order to choose a new MCS because there is a standardized threshold of PER requiring an immediate change of the transmission rate to maintain the link between two devices. For instance, when the propagation channel is degraded, the transition at a lower MCS index, i.e. at a lower bit rate becomes necessary and the throughput is reduced. This value of packet error rate is set by the 802.11n standard to 0.1 for a packet size of 4096 bytes [6].

Since we use a packet size of 1500 bytes and the studies in [7] have shown that the packet error rate varies approximately linearly with the packet size, when the BER is low, the threshold value of the PER that we consider is defined by

$$PER = 0.1\frac{1500}{4096} = 0.0366 \tag{3}$$

In the following paragraphs, the effect of three parameters related to the propagation channel is analyzed; two of the transmitter side (angular spread and angle of departure) and the third is related to the receiver (angle of arrival). The aim is to assess the weight of each parameter on a possible degradation of performance in terms of the maximum data rate the system can select to guarantee the PER threshold. Thereby, simulations are designed in such a way that we change the value of a parameter for different indices of MCS, particularly for MCS 13, 14 and 15. The evolution of the PER versus the channel parameter is then shown to illustrate in which cases a MCS can be used.

Results given below correspond to an analysis performed on the parameters of the first cluster for model D which, according to our previous studies [1], has the greatest impact when compared to the second or the third cluster.

The SNR value used in the simulations was 38 dB. In fact, it is for SNR values between 35 and 40 that we noted the highest dispersion of measured throughputs in function of the received power [1, 8].

B. *Angular Spread (AS) and MCS*

The first observation drawn from Fig. 3 is that the packet error rate decreases when the value of the angular spread increases, i.e. when we have a rich environment between the transmitter and receiver. This propagation environment (with SNR = 38 dB), represented in this case by the angular spread, has no effect when using MCS 13 and 14 corresponding to data rates of 104 Mbps and 117 Mbps if AS > 10°.

MCS 15, which corresponds to a data rate of 130 Mbps, can be used for high values of AS, above 27°. This is not always possible because indoors measurements have shown that the angular spread varies between 10° and 70° [10]. Experimental investigations showed that the global angular spreads ranged between 20° and 70°, based on the location of the transmitter and receiver in Non Line Of Sight (NLOS) environment. The default value defined by the D model for the first cluster is 27.7°.

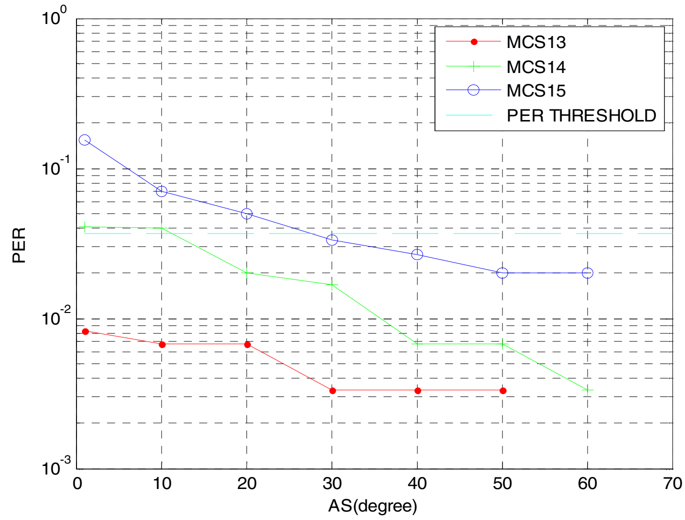

Figure 3. PER versus Angular Spread (AS) for MCS13, 14 and 15. Channel D, with SNR = 38 dB.

C. *Angle of Arrival (AOA) and MCS*

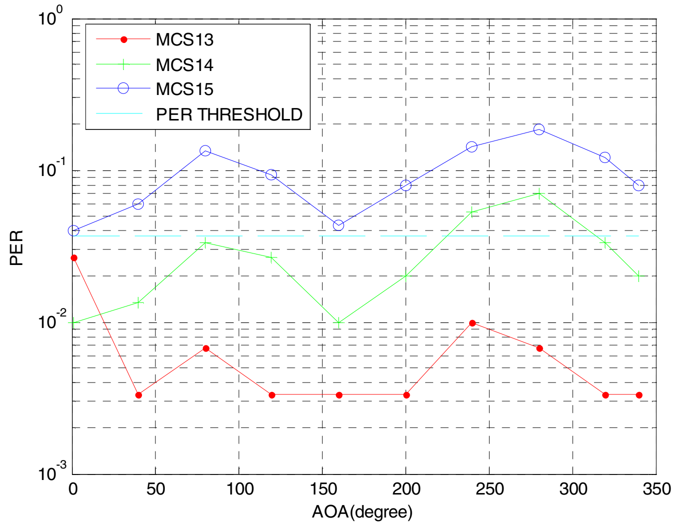

Figure 4. PER versus Angle of Departure (AOA) for MCS13, 14 and 15. Channel D with SNR = 38 dB.

In Fig. 4, the PER is given versus the angle of arrival, measured for the same MCS as previously. Each curve can be approximately obtained by translating vertically the other one. This can be explained by an identical behavior of the system toward the same environment. A maximum PHY bit rate of about 117 Mbps can be achieved for almost any value of AOA i.e. operating with the MCS13 and 14. For MCS 15, the curve is completely above the PER threshold.

PER peaks are reached for values of AOD/AOA of about 90°, which corresponds to the fact that a ray parallel to the antenna array leads to a lower channel correlation that degrades the performance of a link.

D. Angle of Departure (AOD) and MCS

The same remarks can be made in the case of the angle of departure based on Fig.5.

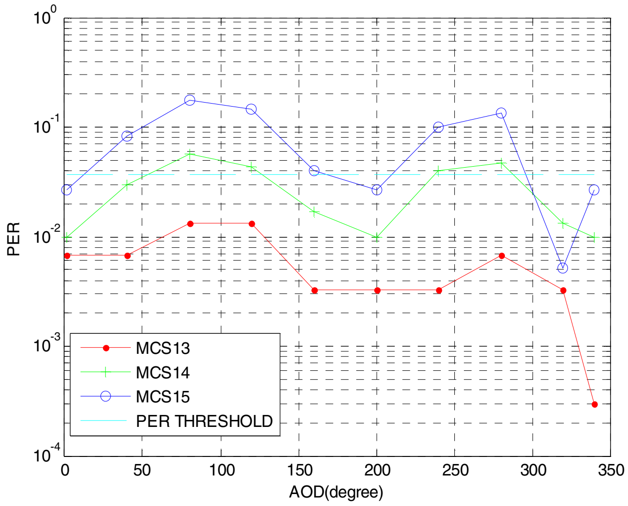

Figure 5. PER versus Angle of Departure (AOD) for MCS13, 14 and 15. Channel D with SNR = 38 dB.

IV. Impact of Two Parameters

In this section, the joint impact of two propagation parameters is considered, called p_1 and p_2. Examples of results give relevant areas, i.e. the pairs (p_1, p_2) where performance in terms of PER is the best.

In Fig. 6, the evolution of the correlation coefficient of the transmit side R_{Tx} versus the angular spread (AS) and the transmitting antenna spacing (d_{Tx}) is presented. R_{Tx} depends on the studied parameters and therefore it is able to describe the behavior of the channel and is correlated to the PER [1]. The correlation coefficient remains high even for relatively great values of the antenna spacing. When the value of the angular spread is small, the R_{Tx} is clearly more sensitive to AS than to the distance between antennas. The distances are expressed in terms of wavelength λ.

In Fig. 7, and as can be expected, the packet error rate follows the same trend as the R_{Tx} (in Fig. 6). It is higher when the spacing between antennas and AS are both low, but a greater spacing between the antennas ($d_{Tx} > \lambda$) can compensate the performance degradation caused by a small value of the angular spread (below 20°).

We find the same trends as previously, i.e. the periodicity of PER, even when the study concerns the relationship between the angle of departure and the spacing between transmitting antennas (Fig. 8) or the angular spread (Fig. 9). We show that high values of the distance between transmitting antennas ($d_{Tx} > \lambda$) may be sufficient to reach a relatively acceptable error rate for any value of AOD. In practice, AOA and AOD are random because the access point (AP) and especially the mobile terminal have a random orientation. To ensure the best performance in all configurations, the recommendation is to increase sufficiently the antenna separation (if we have a linear antenna array of dipoles). The same observation remains valid: values of AS above 40° can ensure a PER not too high.

This shows the importance of the spacing of antennas and the angular spread when compared to the angle of departure.

It should be noted that results similar to those presented above were found when studying the receiving side, i.e. the angle of arrival (AOA), angular spread in reception and spacing between receiving antennas.

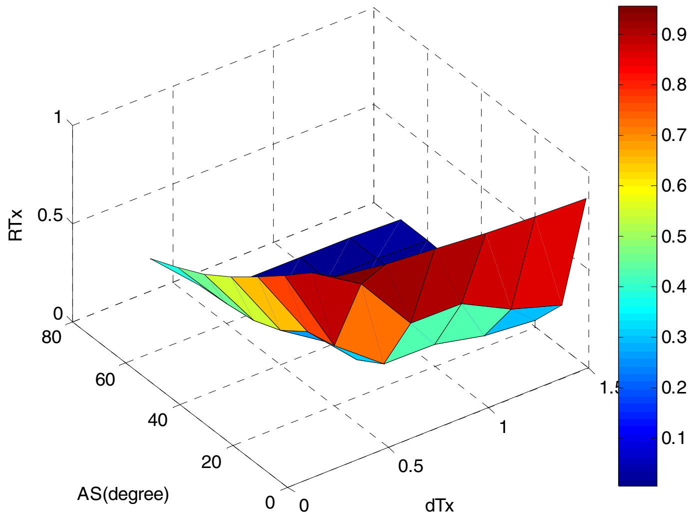

Figure 6. RTx versus Angular Spread and transmitting antennas spacing (dTx in λ).

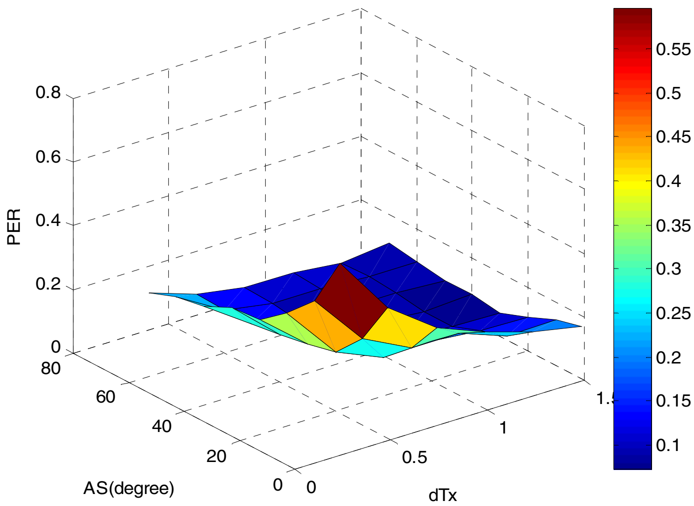

Figure 7. PER versus Angular Spread and transmitting antennas spacing (dTx in λ).

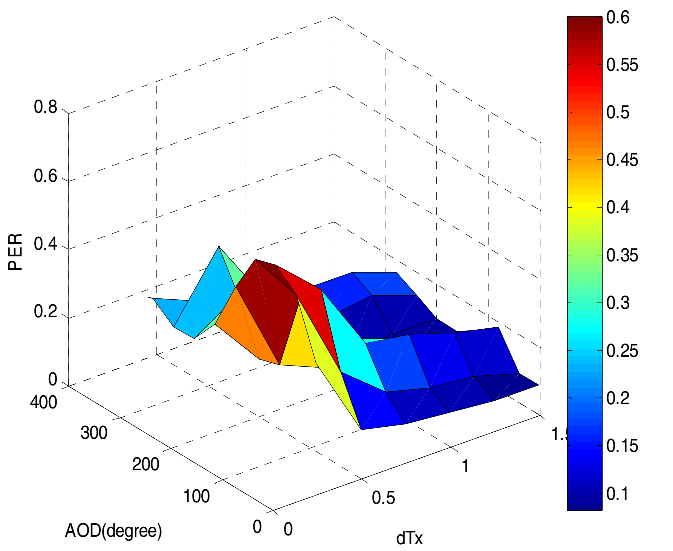

Figure 8. PER versus Angle of Departure and spacing of transmitting antenna (dTx in λ).

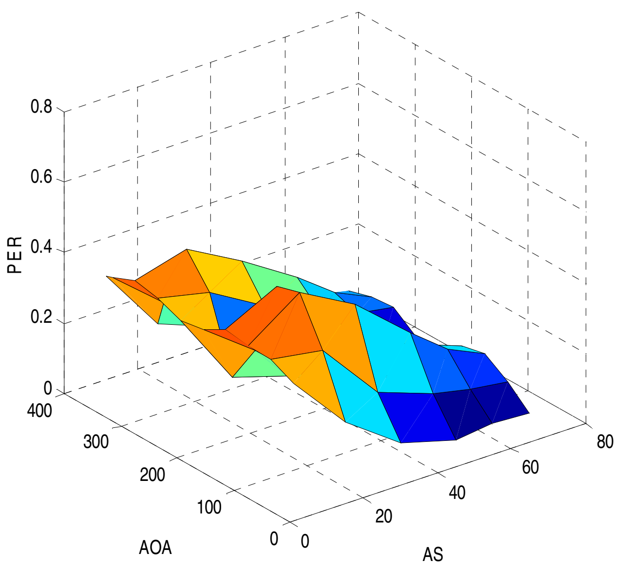

Figure 9. PER versus Angle of Arrival (degree) and Angular Spread (degree)

V. CONCLUSION

In this paper, we have presented an analysis of the IEEE 802.11n MIMO system performance degradation in the indoor environment. Since the received power is not sufficient to justify the dispersion of throughputs even in a non interfered environment, the impact of some parameters of the wireless channel on PER and on the selected MCS has been studied through several examples. From the obtained results, we can conclude that for a 20 MHz bandwidth with a 2x2 MIMO system, and for a same received power, it is not always possible to achieve a bit rate of 130 Mbps. A lower MCS has to be used, corresponding to a throughout reduction experienced by the user. On the other hand, an analysis of the simultaneous effect of two parameters has showed the importance of the distance between antennas and the angular spread compared with the angle of departure / arrival to make the performance less sensitive to the channel parameters dispersion. These results could be also useful to define new rate adaptation mechanisms, based on channel correlation estimates.

In further studies, it could be also interesting to analyze the impact of the antenna pattern and polarization to decorrelate the signals instead of increasing the antenna spacing.

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