CAPACITY ANALYSES FOR IEEE 802.11N NARROWBAND AND WIDEBAND CHANNEL MODELING

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Abstract: In this paper we investigate the channel capacity when MIMO (Multiple Input Multiple Output) technology is employed for wireless communication systems that are designed under IEEE 802.11n conditions. First, we emphasis the methods of modeling the NLOS (Non Line of Sight) narrowband and wideband communication channel. Afterwards, the channel capacity behavior is analyzed as a function of ray propagation physical parameters given in the standard, such as: AoA/AoD (Angle of Arrival/ Angle of Departure), AS (Angle Spread), number of clusters, number of antennas and inter – element distance. The spatial correlation properties are also incorporated in our investigation.

Keywords: *narrowband channel modeling, wideband, capacity, spatial correlation.*

I. INTRODUCTION

Many research activities are carried out in the field of MIMO (Multiple Input Multiple Output) technology, due to the great improvement in what concerns the channel capacity, throughput, link reliability and coverage area without the need for extra operational frequency bandwidth.

Even if most research areas are regarding the multi-antenna system itself (eg. signal processing, coding techniques, etc.), the interest in investigating the channel modeling methods is more and more outstanding. This is due to the fact that performing the simulations over a channel model how's results are in great agreement with the measurements obtained from the channel sounding campaigns, high- performances MIMO communication systems can be designed and system performances can be accurately predicted; sometimes the simulations are less time consuming and less costly.

Most of the researches of MIMO channel capacity are based on the narrowband flat fading MIMO channels, such as in [1], [2] and [3], but recently interest has turned on the modeling approaches for wideband frequency-selective communication MIMO channels. The modeling of the wideband channel is needed for MIMO channel because MIMO systems are suitable for high data rate wireless communication systems, where the bandwidth is usually large, which encounters frequency- selective channels [4]. Wideband channel investigations can be found in [4], [5], [6].

In this paper we model the multipath communication channel for NLOS (Non Line of Sight) indoor environments based on the PDP (Power Delay Profile) given in IEEE 802.11n standard for the narrow and wide band approach. In our channel capacity analysis we take into account the spatial correlation properties of the radio environment, because it was found that capacity of the MIMO channel is overestimated when spatial correlation is not considered [7].

Kai Yu, in [9], combined the Kronecker structure with a simple COST 259 single-input single output channel model in order to extend the narrowband to the wideband approach. Based on [8] and [9], we extend the channel capacity analyses for the narrowband multi - antennas systems operating under the MIMO WiFi standard, IEEE 802.11n, to the wideband, bringing forward the corresponding channel modeling.

For our simulations we consider the following assumptions: a ULA (Uniform Linear Array) geometry at both transmitter and receiver, uniform power allocation scheme and CSI (Channel State Information) only at the receiver.

The paper is organized as follows: section II describes the IEEE 802.11n channel modeling approach based on Saleh- Valenzuela model, Kronecker model and spatial correlation properties. Section III and section IV provide the method of modeling the narrowband and wideband MIMO channel matrix, respectively, over the PDP and they give the channel capacity. In the end the obtained results are presented and conclusions are drawn.

II. CHANNEL MODEL

The following section describes the channel modeling adopted by IEEE 802.11n.

First, this standardized channel model was developed for mostly indoor propagation environments where MIMO systems operate in WLANs. The measurement campaigns that give the physical propagation parameters were carried out in spaces such as small and large office areas, small and large residential homes and large areas such as airports or factories. Eventually, the channel model gives the following propagation parameters for 6 propagation environments noted from A to F [8]: number

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of multipath components (MPC), PDP, number of clusters, angle of departure and arrival, angle spread and PAS (Power Azimuth Spread). The number of clusters takes values of 2, 3, 4 and 6, each environment being characterized by different RMS (Root Mean Square) delay spread: from 15µs for the smallest environment to 150µs for the largest propagation surrounding. Each cluster is composed by a maximum number of 18 taps (spaced by minimum 10ns) and a minimum of 2 taps. The geometry of the physical propagation parameters is depicted in figure 1.

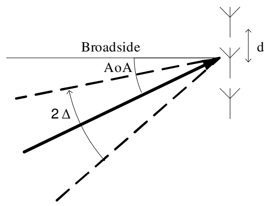

Figure 1. AoA and AS (Δ) angles and d – interelement spacing

The IEEE 802.11n channel is a combination of two models: the statistical Saleh- Valenzuela model which is based on the MPC clustering in the angular domain and the analytical Kronecker model which, due to the rich scattering in the propagation environment, it considers that the spatial correlation properties at the transmitter are independent from those at the receiver. Besides, in [15] it has been shown that channel models that don't consider clusterisation of the MPC overestimate the channel capacity. A cluster is considered to be a group of rays that have the same statistic physical propagation parameters.

With the help of Kronecker dissociation assumption, the MIMO channel matrix can be computed with the help of Kronecker product between the spatial correlation matrices at transmitter and receiver and Rayleigh matrix whose elements are i.i.d. (independent and identically distributed), given by relation (1):

$$[H] = \{[R_{Tx}] \otimes [R_{Rx}]\}^{1/2} [H_{iid}] \qquad (1)$$

Where R_{Tx} and R_{Rx} are the correlation matrixes at transmitter and receiver, respectively and H_{iid} is the i.i.d. matrix. The structure of R_{tx} and R_{Rx} matrices is as in relation (2):

$$R_{TX} = \begin{bmatrix} 1 & \rho_{21}^* & \rho_{31}^* \\ \rho_{21} & 1 & \rho_{32}^* \\ \rho_{31} & \rho_{32} & 1 \end{bmatrix} R_{RX} = \begin{bmatrix} 1 & \rho_{21}^* & \rho_{31}^* \\ \rho_{21} & 1 & \rho_{32}^* \\ \rho_{31} & \rho_{32} & 1 \end{bmatrix} \qquad (2)$$

Where ρ_{21} is the correlation coefficient between antenna element no. 2 and no.1 and is given by relation 3:

$$\rho = R_{XX}(D) + jR_{XY}(D) \qquad (3)$$

Where R_{xx} and R_{xy} are cross- correlation function between the real parts and cross- correlation function between the real and imaginary part, respectively; $D = 2\pi d/\lambda$ with d being the normalized interelement spacing and λ the wavelength.

In research activities that deal with clusters detection and statistics about angle of arrival, such as [10], it was found that the angle of arrival within a cluster for indoor environments follows the Laplacian distribution, among others distributions such as Gaussian and Uniform. Thus, the correlation coefficients at transmitter and receiver given by (3) were computed, keeping this distribution, specified also in [11].

III. NARROWBAND MIMO CHANNEL MODELING AND CAPACITY

For the narrowband situation, when the signal bandwidth is sufficiently small when compared with the coherence bandwidth, the channel response is similarly affected over the entire bandwidth.

The narrowband MIMO channel model expresses the channel gain h_{jk} between the receive antenna j and transmit antenna k as one single tap [9], the signal seen at the receiver being a summation off all taps [8], [12]. In order to obtain the global narrowband MIMO channel matrix, the MIMO channel matrix for each tap is computed under the IEEE 802.11n specifications using (4) and then a summation is performed.

$$H_i = \sqrt{P_i}\left(\sqrt{\frac{K}{K+1}}H_{LOS_i} + \sqrt{\frac{1}{K+1}}H_{NLOS_i}\right) \qquad (4)$$

Where P_i is the power of tap i, H_{LOSi} and H_{NLOSi} is the channel matrix for LOS (Line of Sight) and NLOS propagation, respectively and K is the Ricean factor. H_{NLOSi} is computed with (1). Thus, the narrowband MIMO channel matrix is given by (5), where τ_i is the delay of tap i.

$$H = \sum_{i=1}^{L} H_i = \sum_{i=1}^{L} h_{jk}(\tau_i) \qquad (5)$$

The capacity of a narrowband channel when uniform power allocation scheme is employed over the N_{tx} transmit antennas is:

$$C = log_2\left\{det\left(I_{N_{rx}} + \frac{SNR}{N_{tx}}HH^H\right)\right\} \text{[bps/Hz]} \qquad (6)$$

Where I_{Nrx} is an identity matrix of dimension N_{rx} x N_{tx}, H is the channel matrix given by (5) and $(\bullet)^H$ is the Hermitian transpose of •.

IV. WIDEBAND MIMO CHANNEL MODELING AND CAPACITY

For new day communication systems the bandwidth is a principal matter and, in the same time, channel is being frequency dependent due to the multipath characteristics of the propagation channel.

Based on [9], we extend the narrowband modeling to the wideband approach, by applying the Kronecker structure of correlation matrix to each tap i:

$$R_H^i = R_{Tx}^i \otimes R_{Rx}^i \qquad (7)$$

The wideband representation with respect to frequency is:

$$H(f) = \sum_{i=0}^{L-1} H_i \, exp(-2\pi \frac{fi}{N}) \qquad (8)$$

Where H_i is the channel matrix for tap i and N is the number of frequency flat subchannels in which the wideband channel is divided in [13].

The capacity analyses of the wideband are realized following [14]:

$$C = \frac{1}{N} \sum_{n=0}^{N-1} log_2 \, det\left(I_{N_{rx}} + \frac{SNR}{N_{tx}} H_i (H_i)^H \right) \qquad (9)$$

V. EXPERIMENTAL RESULTS

In this section is analyzed the capacity behavior for narrowband channel as a function of physical propagation parameters, of inter-element spacing at both transmitter and receiver and of the number of active antenna elements used at the link ends. Then, the CDF (Cumulative Distribution Function) of capacity for the wideband channel is discussed.

The channel capacity is mainly influenced by 4 factors such as: spatial correlation degrees, which in turn are dependent of physical propagation parameters, number of antennas employed at Tx and Rx and inter – element spacing.

If the spatial correlation at receiver and transmitter is lower, such that the diversity order is increased, the channel capacity can be improved.

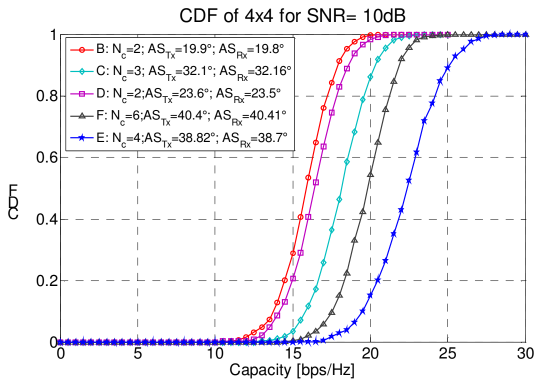

Figure 2. Capacity CDF for 802.11n channel models: B, C, D, E and F

The CDF capacity results obtained for the IEEE 802.11n narrowband modeling channels when a 4x4 MIMO system is employed with 0.5λ inter-element spacing at T_x and R_x are depicted in figure 2. For MIMO technology, when the number of clusters (N_c) increases, the capacity increases as well. This means that when the propagation environment is rich in scattering objects that create multiple propagation paths, which can be grouped in multiple clusters, the channel capacity is higher. The capacity analyses were carried over 1000 channel realizations of H.

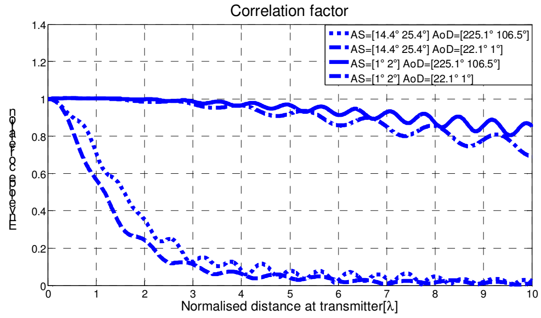

Figure 3. AoA/AoD and AS influence upon correlation coefficients

If figure 2 and 3 are analyzed, one can conclude that the AS has greater influence on spatial correlation coefficients than AoA/AoD: the higher the AS is, the lower the correlation coefficient gets; this results in dependence of capacity mainly on AS: if AS increases, the capacity increases.

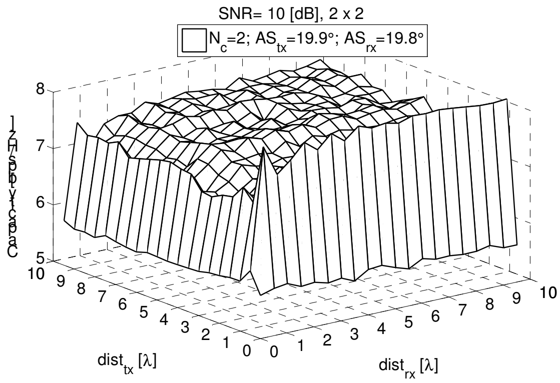

Figure 4. Capacity variation vs. inter-element spacings

The capacity results shown in figure 4 were computed for Model B which is characterized by N_c=2, AS_{Tx}= 19.9^o and AS_{Rx}=19.8^o. So far it was stated that in order to obtain a high channel capacity the spatial correlation degree between the received signals has to be low. From figure 3 it can be seen that this condition is fulfilled when the space between antenna elements at Tx and Rx is high. First of all, inter-element spacing cannot be very high because of the dimension constraints of the user equipment. Secondly, from figure 4 one can see that even if the inter-element distance at Tx and Rx gets higher, after a distance threshold the channel capacity approaches to a certain value, depending on the propagation environment.

	Dist_rx	Dist_tx	Capacity[bps/Hz]
B	0.5	0.5	8.285
C	1.5	2.5	8.517
D	2.5	1	9.533
E	1	0.5	10.42
F	0.5	0.5	10.33

Table 1. Maximum capacities and their corresponding distances

The maximum channel capacity in bps/Hz is obtained for the following antenna spacing at transmitter (dist_tx) and at receiver (dist_rx) and they are listed in table 1. The analyses are carried out for a MIMO system of 2x2, but in the implementation the number of antenna can be set by the user. SNR level is 10 dB.

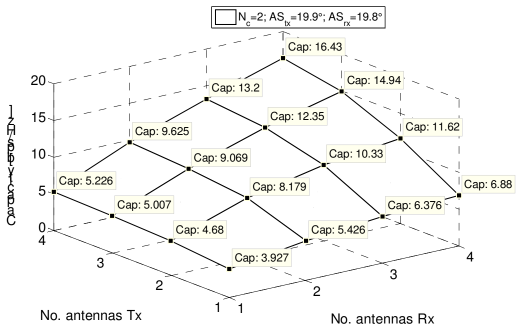

Figure 5: Capacity variation vs. no. of antennas (d=0.5λ) for RMS=15μs and SNR=10dB

The greatest capacity gain is obtained when a symmetric MIMO system is used, rather than for an asymmetric one. Under the conditions specified in figure 5, for a symmetric configuration greater than 4x4 the capacity gain is about 2bps/Hz when an extra antenna is added at T_x and R_x, while for an asymmetric one the gain is less than 1bps/Hz. For the rest of the propagation environments, the capacity behavior is similar: it significantly increases with the increase of T_x and R_x antennas number until a threshold above which the use of more antennas doesn't defend the capacity gain.

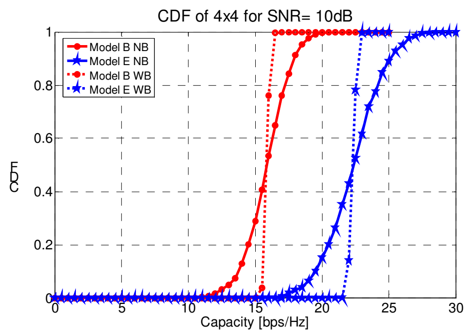

Figure 6. Narrowband and wideband capacity for model B and E

Our wideband channel capacity results confirm those in the literature [4], [5], that frequency selectivity of the channel has only a small influence on the mean capacity when compared with the frequency flat case. The main difference is that the higher the N is the more smoothly channel capacity results are. Results from figure 6 are obtained for N= 64.

VI. CONCLUSIONS

In this paper, narrowband and wideband indoor wireless propagation channels were modeled when MIMO technology is used. The capacity behavior was analyzed as a function of real propagation parameters: thus it was found the dependence with number of ray clusters, spatial correlation coefficients and ray propagation geometry. Figure 2 and 3 show that the correlation coefficients depend strongly on both AS and inter-element spacing and less on AOD/AOA. A higher cluster angular spread and inter – element spacing result in lower correlation coefficients, which in turn guarantees higher channel capacity, as in figure 4. Though, the dependence of channel capacity for real propagation environments is not linear, but is limited by the number of antenna elements and inter-element spacing.

Finally, it was shown that wideband and narrowband channel have about the same channel behavior.

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