MIMO Linear Array System Resource Management by Diagnosing the Optimal Configuration

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***Abstract* — The use of multiple antennas at transmitter/receiver side and of spatial diversity, increases the spectrum efficiency and overcomes the multi path propagation effects in a MIMO (Multiple Input Multiple Output) system. Based on the propagation parameters, from IEEE 802.11n specifications for 5 types of transmission environments, and on MatLab 7.1 simulation results, we propose the adaptive optimization of linear antenna array by means of number of active elements, elements spacing and maximum capacity.**

***Keywords* — adaptive, capacity, channel models, element spacing, MIMO, optimization**

I. Introduction

THE use of multiple antennas at transmitter/ receiver ends in a MIMO (Multiple Input Multiple Output) system, brings great improvements in what concerns the transmission rates and decrease of interferences due to the use of spatial diversity schemes in reach scattering environments.

The presence of many reflections in the propagation environment makes the MIMO system to be more efficient, by creating multiple independent propagation sub-channels. In this way the obtained MIMO capacity can achieve values of n=min (N, M) times greater than the SISO capacity; N and M being the transmitting and receiving number of elements, respectively. The system capacity depends on the sub-channel number, the characteristics of antenna array (number of elements, element spacing, etc.), SNR (Signal to Noise Ratio) and characteristics of propagation environment.

In order to analyze a wireless system as realistic as possible, it is absolute necessary to be aware of the specific ray propagation parameters in different channels such as: AoA (Angle of Arrival), AoD (Angle of Departure), CAS (Cluster Angle Spread), number of clusters and power azimuth spectrum.

Kronecker model is used to analyze the MIMO channel, based on its separability assumption with regard to channel matrix correlation.

In this paper, based on the physical parameters of ray propagation described in IEEE 802.11n specification for various channel types, and on transmission/ reception correlation channel matrixes we derive the corresponding channel matrixes, and finally the system capacity. For each propagation environment we propose an optimal number of antenna elements and elements spacing needed to guarantee a maximum capacity under imposed condition upon the system.

The presented paper is organized as follows: it starts with an introduction section where we present a brief introduction to the subject; the Section II is a theoretical approach where we mention the basic information regarding the MIMO channel model, IEEE 802.11n specifications, the Kronecker model and the channel capacity; Section III is represented by the implementation steps; in Section IV we describe the system resource optimization with respect to the test profile depiction, simulation results and optimum configuration detection for a MIMO linear antenna array.

II. Theoretical approach

A. MIMO channel model

A MIMO system is composed of N transmit and M receive antenna elements as shown in the figure below.

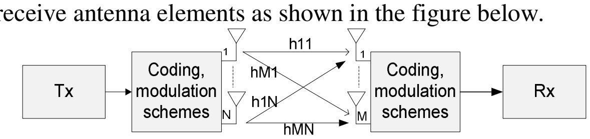

Fig. 1. MIMO system principle diagram

For a time invariant channel, the corresponding channel matrix can be expressed as:

$$y = \sqrt{P}Hx + n \qquad (1)$$

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where, y is the received vector, x is the transmitted vector, H is N x M channel matrix, $\sqrt{P}$ is the transmit signal power on each antenna element [1].

The channel matrix H that describes the connection between the transmitter and the receiver can be expressed as:

$$H = \begin{pmatrix} h_{11} & h_{12} & ....h_{1N} \\ h_{21} & h_{22} & ....h_{2N} \\ . & . & . \\ . & . & . \\ h_{M1} & h_{2} & ....h_{MN} \end{pmatrix} \quad (2)$$

where, h_{MN} is the complex transmission coefficient from antenna N to antenna M.

B. IEEE 802.11n

The TGn 802.11n channel model was developed for indoor environments at 2GHz and 5GHz, emphasizing the MIMO applications in WLAN (Wireless Local Area Networks) networks. It specifies a set of 6 channel types, A to F, corresponding to each propagation environment, from small offices to large areas.

In order to derive the channel matrix as real as possible, we use the physical ray propagation parameters from the IEEE 802.11n specifications [2]. The considered parameters are: AoA (Angle of Arrival), AoD (Angle of Departure), CAS (Cluster Angle Spread), number of clusters and power azimuth spectrum; they are specific to each of one of the 6 types of indoor channel model. For the case of 2 clustered model, these parameters are shown in the figure bellow:

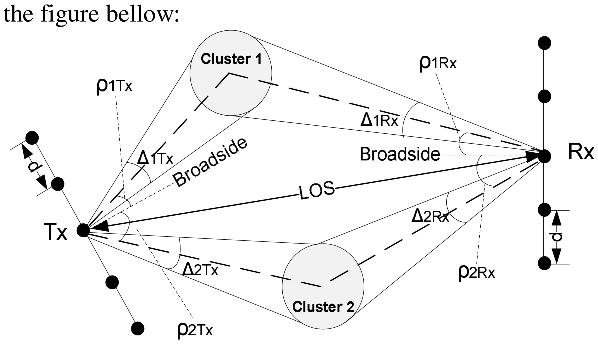

Fig. 2. Two clustered model geometry

In fig. 2, φ_{1Rx}, φ_{2Rx} are the AoAs and φ_{1Tx}, φ_{2Tx} are AoDs for the corresponding clusters and d is the elements spacing, in wavelengths.

The cluster concept is based on the assumptions from [3] and it is defined as a group of multi path components that have the same propagation parameters. It was also shown in [2] that the power profile of rays within each cluster has a Laplacian distribution.

C. The Kronecker approach

The channel matrix that characterizes the propagation environment is given by:

$$H = \sqrt{\frac{1}{1+K}}H_F + \sqrt{\frac{K}{1+K}}H_V \quad (3)$$

where, K is the Rice factor, H_F and H_V are the matrixes corresponding to LOS and NLOS conditions, respectively.

For the Rayleigh fading we use the Kronecker model. The correlation matrixes corresponding to T_x and R_x are derived as a function of power distribution and of geometry parameters. The model assumes the separation of the correlation coefficients matrix at the T_x (R_{Tx}) from the one at R_x (R_{Rx}), the channel correlation coefficients matrix being equal to the Kronecker product of those two matrixes, as in equation bellow:

$$R_H = R_{Tx} \otimes R_{Rx} \quad (4)$$

The elements of transmit and receive correlation matrixes are defined by:

$$[R_{Rx}] = [\rho_{Rxij}]$$
$$[R_{Tx}] = [\rho_{Txij}] \quad (5)$$

where, ρ_{Txij} are the correlation coefficients between the i^{th} and j^{th} elements at transmitter and ρ_{Rxij} are the correlation coefficients between the i^{th} and j^{th} elements at the receiver.

Using the Kronecker approach, the channel matrix can be written as:

$$[H] = \{[R_{Tx}] \otimes [R_{Rx}]\}^{1/2}[H_{iid}] \quad (6)$$

where, H_{iid} is a vector of random complex Gaussian variables, of unit variance and zero mean.

The elements of R_{Tx} and R_{Rx} correlation matrixes are derived based on the concepts described in [4], and they are summarized in relations bellow:

$$R_{xx}(D) = J_0(D) + 4\sum_{k=1}^{N_c}\frac{Q_{L,k}}{\sigma_k\sqrt{2}}\sum_{m=1}^{\infty}\frac{J_{2m}(D)}{(\frac{\sqrt{2}}{\sigma_k})^2+(2m)^2}\cos(2mAoA_{0,k}) \quad (7)$$
$$\{\frac{\sqrt{2}}{\sigma_k}+\exp(-\frac{\Delta_k\sqrt{2}}{\sigma_k})[2m\sin(2m\Delta_k)-\frac{\sqrt{2}}{\sigma_k}\cos(2m\Delta_k)]\}$$

$$R_{xy}(D) = 4\sum_{k=1}^{N_c}\frac{Q_{L,k}}{\sigma_k\sqrt{2}}\sum_{m=0}^{\infty}\frac{J_{2m+1}(D)}{(\frac{\sqrt{2}}{\sigma_k})^2+(2m+1)^2}\sin[(2m+1)AoA_{0,k}] \quad (8)$$
$$\{\frac{\sqrt{2}}{\sigma_k}+\exp(-\frac{\Delta_k\sqrt{2}}{\sigma_k})[(2m+1)\sin[(2m+1)\Delta_k]+\frac{\sqrt{2}}{\sigma_k}\cos[(2m+1)\Delta_k]]\}$$

In equation (7) R_{xx} is the cross- correlation function between the real parts of the complex baseband signals received at two omni- directional antennas separated by distance d, $D = 2\pi\frac{d}{\lambda}$, PAS is the Power Azimuth Spectrum (in our case is Laplacian) and ϕ is the AoA. In equation (8), R_{xy} is cross- correlation function between the real and imaginary parts of the same complex baseband signal. σ_k is the standard deviation and is considered equal to AS of the k^{th} cluster. $AoA_{0,k}$ is the mean angle of arrival that corresponds to the specific environment and k^{th} cluster. $\Delta_k = \sqrt{3}AS$ is the angle spread of the k^{th} cluster. N_c is the number of clusters and $J_0(D)$ is the Bessel function of the first kind and order zero. $Q_{L,k}$ are constants that ensure that PAS_L (ϕ) respects the probability distribution function conditions [4].

TABLE 1: THE CAPACITY AND INTER- ELEMENT SPACING RESULTS

Model	Param.	2x2	2x3	2x4	3x2	3x3	3x4	4x2	4x3	4x4
B	d_{tx}	2.8	2.3	2.9	0.4	0.4	0.4	0.7	0.7	0.7
	d_{rx}	1.8	1.8	0.8	1.8	2.1	2.1	1.8	2.1	2.3
	C_{max}	7.57	9.27	10.62	10.82	14.58	17.00	11.63	16.61	20.61
C	d_{tx}	0.9	0.9	0.9	1.5	2.2	2.2	0.6	0.6	2.2
	d_{rx}	0.5	0.4	0.6	1.1	0.4	0.6	2.4	0.4	0.6
	C_{max}	7.62	12.06	13.79	8.02	14.26	17.81	9.01	15.58	20.40
D	d_{tx}	0.2	2.2	2.3	0.3	0.3	0.3	0.2	0.5	0.6
	d_{rx}	0.1	0.3	0.2	2.1	0.3	0.3	2.0	0.3	0.3
	C_{max}	7.12	10.65	12.05	9.52	18.51	20.50	10.12	19.33	21.41
E	d_{tx}	0.5	1.8	1.8	0.3	0.3	0.3	0.2	0.2	0.6
	d_{rx}	0.2	0.4	0.3	0.7	1.4	0.7	0.6	0.8	0.8
	C_{max}	6.95	8.49	9.62	11.09	14.88	17.04	11.5	15.80	18.18
F	d_{tx}	2.4	1.9	1.9	0.5	0.5	0.5	0.2	1.6	1.6
	d_{rx}	1.3	0.3	0.5	1.9	0.5	0.6	1.9	0.5	1.6
	C_{max}	7.04	11.02	12.49	10.11	17.65	19.75	10.69	19.25	24.23

For a linear system configuration, the correlation coefficients are given by:

$$\rho = R_{xx}(D) + R_{xy}(D) \tag{9}$$

D. *The channel capacity*

The channel capacity is defined as the maximum transmission rate than can be achieved at a specified threshold probability error. If there is no CSI (Channel State Information) at the transmitter the only way to distribute the transmit power is by using the uniform power allocation schemes on the N transmit elements. Giving N transmit antennas, the theoretical capacity, C, is given by:

$$C = \log_2 \det[I + (\frac{r}{N_t})HH'] \tag{10}$$

Where, I is an identity matrix of M x M dimension, H is the channel matrix, H' is the conjugate transpose of H and r is the SNR.

III. IMPLEMENTATION STEPS

In order to obtain the desired results, we follow the next MatLab 7.1 implementation steps:

- the propagation environment is selected;
- based on the specific propagation parameters, we derive the correlation coefficients using equation (7), (8) and (9), where D takes values from 0λ and 10λ;
- considering the following input parameters: correlation coefficients, system configuration given by transmit/receive elements number and the domain within the inter element distance varies in [0.1λ; 4λ] , we derive for every type of environment the channel matrix;
- based on the channel matrix, we compute the system capacity (bps/Hz); from equation (6) it can be noticed the randomness of H, in consequence, the randomness of C. In order to obtain a real value of capacity, we compute the channel matrix and the capacity over a 2000 channel realizations; finally we perform a mean of capacity.

We perform the simulation in order to determine the optimum configuration and the inter- element spacing that give the maximum capacity in different propagation environments.

With this purpose, we simultaneously change the transmitter and receiver inter- element spacing and derive and propose the optimum capacity for every combination of this distances.

IV. SYSTEM RESOURCE OPTIMIZATION

For a radio system that respects the IEEE 802.11n conditions, this paper proposes to identify an optimal configuration of the MIMO linear system array.

The capability of multiple antenna systems to gradually modify its configuration as a function of the propagation environment, shows, on one hand, the potential of the architecture to automatically adapt itself to the radio channel conditions and, on the other hand, its ability to optimally manage its resources.

In this paper, by the resource management we mean the identification of a MIMO system configuration that has minimal number of transmit/receive antennas and elements spacing, dependent of different characteristics of radio channel, user applications requirements and IEEE 802.11n recommendation with regard to radio channel bandwidth used by transmission technology.

A. *Test profile depiction*

The radio channels that we performed the tests for are characterized by 5 of the early mentioned spatial models (B, C, D, E and F). These models give the specific physical behavior of the rays' propagation in a WLAN mobile indoor environment. The channel models compliance with IEEE 802.11n recommendation are implemented using MatLab 7.1.

In order to identify the appropriate NxM linear array configuration, for this kind of system we simultaneously sweep out both the transmitter and receiver elements spacing within [0.1λ, 4λ] domain. In the test scenarios, the considered sweep step of inter-element distance is 0.1λ.

TABLE 2: THE PROPOSED SYSTEM CONFIGURATION

Configuration parameters for the tested architectures					
Architecture to be tested	IEEE 802.11n				
The minimum required debit per WLAN cell [Mbps]	100				
OFDM channel bandwidth [MHz]	10				
The minimum spectral efficiency [bps/Hz]	10				
SNR at receiver [dBmW]	15				
Spatial channel type	*B*	*C*	*D*	*E*	*F*
Optimal configuration [NxM]	2x4	2x3	2x3	3x2	3x2
Antenna spacing at T_x [λ]	2.9	0.9	2.3	0.3	0.5
Antenna spacing at R_x [λ]	0.8	0.4	0.2	0.7	1.9

Not only the reduced sizes of the equipments, but also the operating bandwidth of WLAN systems (ISM, UNII-I) represent limitations in deciding the appropriate antennas number for linear architectures. As a consequence, the number of elements that can be active, give configuration of maximum 4x4.

Given a 10 MHz bandwidth for OFDM channel, a SNR (Signal to Noise Radio) of 15 db at receiver and a site survey that requires a 100 Mbps minimum throughput per cell (witch is the minimum request for a MIMO system in WLAN technology), the minimum needed spectral efficiency given by relation (10) is 10 bps/Hz.

B. Simulation results

Knowing that the mobile unit crosses all 5 described indoor channels and that the system is capable to translate the characteristics of the propagation environment into a channel matrix that corresponds to a specific channel, we obtain the following results for an N x M configuration with respect to inter-element distances and maximum capacities in a WLAN cell.

With the early presented and imposed conditions, for the linear elements architectures we select the following configurations presented in table 2.

If we take as an example model C, with 2x3 system configuration and the inter-element distance of 0.9 at transmitter and 0.4 at receiver, the system can be depicted as in figure bellow:

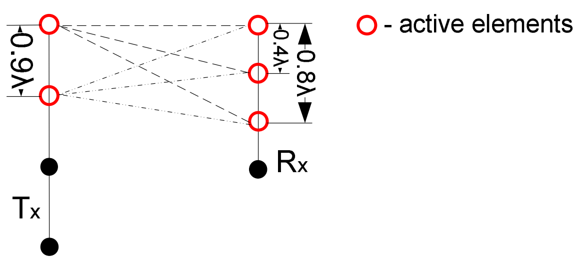

Fig. 3. Optimized configuration for model C

C. Optimum configuration detection for a MIMO linear antenna array

Analyzing the presented results in tables 1 and 2, for the tested architecture we can draw the following conclusions:

1. The simulation results confirm that for every channel model a maximum capacity can be reached with a maximum number of antenna elements; in our case capacity is maximum for a configuration of 4x4;
2. A fixed value of inter-element spacing (for example: λ/4, λ/2 or λ) does not guarantee a maximum spectral efficiency for the used radio channel, the simulation results showing the need to adjust the antenna spacing to the characteristics of the propagation environment.
3. The radio channel characteristics and the minimum conditions required enforce the system to activate a certain number of antenna elements placed at a specific distance one of another. So, the optimal number of elements varies from a configuration of 2x3, to one of 2x4 or 3x2.
4. The selection of the optimal inter-element spacing and the activation of a specific number of elements from the linear array as a function of the type of the channel and the condition imposed to the system, confirm the need of architectural adaptation and thus the efficient use of the system's resources.

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