MIMO CAPACITY SIMULATION IN CELLULAR ENVIRONMENT WITH A RAY MODEL

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Abstract : MIMO (Multiple Input Multiple Output) systems theoretically enable to increase transfer rate by exploiting multipaths of the channel propagation. Here, we show how to estimate MIMO capacity in cellular environment thanks to a ray propagation model for different antennas schemes.

Keywords: MIMO capacity, propagation channel, mobile antennas.

1. Introduction

Based on the use of transmission and reception antenna arrays (*Figure 1*), the MIMO (Multiple Input Multiple Output) systems are now considered as a leading possibility to increase the capacity of communications. This technology allows to widen the information transfer rate without increasing the transmission power nor the frequency range allocated by taking advantage of multiplicity and diversity [1]. In theory, the channel capacity i.e. the maximal transfer rate without errors (in bit/s/Hz), increases linearly with the number of transmission and reception antennas.

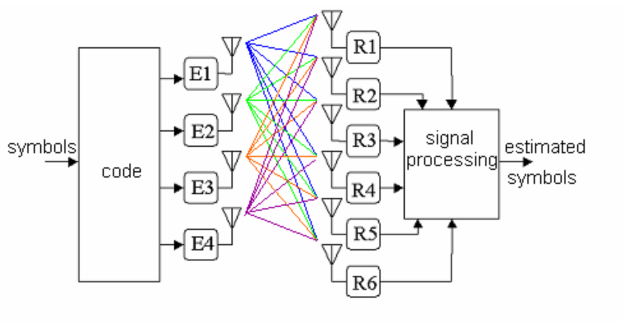

Figure 1 : illustration of a 4 transmitters and 6 receivers MIMO system

We propose here a study of MIMO channel capacity in an urban environment. Several techniques are developed to describe the propagation channel in outdoor, such as ray models [2, 3], geometrical models [4, 5, 6, 7], or high resolution methods [8, 9, 10]. We use a 3-D ray model which gives attenuation, direction of departure, and direction of arrival of each ray in a chosen dynamic. It uses a real environment based on IGN (Institut Géographique National) data.

We have simulated MIMO channel capacity in cellular environment for different antennas schemes using space diversity.

Part 2 introduces the propagation model GRIMM (Geometrical Ray Implementation for Mobile propagation Modelling) used in this paper, and presents capacity computation. Part 3 describes the material used (design and characteristics of antennas) and the simulation conditions, among others antennas positioning. At last, part 4 collects simulation results.

2. Propagation model

Radio propagation channel is the transmit support of the radio-mobile communications systems. This key link of the simulation chain must be modelled carefully to obtain accurate simulation results.

We use the propagation model GRIMM [11,12] developed by France Telecom. This 3-D model combines ray launching and ray tracing methods that allows a considerable reduction in computation times. The propagation channel modelling is made with geographical data bases including information on external building structures. Phenomenon considered are : reflection on wall buildings, horizontal and vertical diffractions, transmission through vegetation and buildings. Penetration into buildings and diffractions due to the wall irregularity are neglected. This type of model allows the extraction of all the characteristics of the channel and includes the topography of the chosen environment.

3. Simulation conditions

3.1 Capacity estimation

We considered a narrowband channel. Assuming no channel state information at the transmitter side, its capacity is given by [13] :

$$C = log_2\left[det\left(I_{N_R} + \frac{\rho_s}{N_T} HH^H\right)\right] \quad (1)$$

where N_T is the number of transmitters and N_R the number of receivers. H is the normalized channel matrix, whose

entries have unit average power. The average SNR is denoted ρ_s, I_{NR} the identity matrix of dimension N_R, and $(.)^H$ denotes the complex conjugate transpose.
The complex transfer function $H_{p,q}$ of the physical channel connecting the pth transmitting element and the qth receiving element is :

$$H[p,q]=\sum_{k=1}^{K} u_k e^{j\Phi_k} \times e^{j\frac{2\pi}{\lambda}\left(D_p(k)+D_q(k)\right)} \qquad (2)$$

where $u_k\, e^{j\Phi_k}$ is the complex amplitude of the kth ray, and K the total number of rays.

$$D_i(k) = x_i \cos\theta_k \cos\varphi_k + y_i \cos\theta_k \sin\varphi_k + z_i \sin\theta_k \qquad (3)$$

with antenna coordinates (x_i, y_i , z_i) and elevation angle θ and azimuth angle φ.
The average level of the receive signal is calculated for a SISO (Single Input Single Output) system with real antenna in transmission and isotropic antenna in reception.

3.2 Antennas

The base station antenna (*Figure 2*), designed in the PAESTUM RNRT project [14], is composed of dipole arrays. There are 6 elements. Note that the boundary element (columns 5 and 6 in *Figure* 2) were not used. Each element is made of a vertical column of 4 dipoles. The base station antenna works in 1920 MHz - 1980 MHz and 2110 MHz - 2170 MHz frequency bands. They have 45° of radiation pattern aperture.
The mobile station antenna is made of two PIFA (Planar Inverted-F Antenna) elements, arranged from head to foot (*Figure 3*). It works between 1800 MHz and 2400 MHz. A prototype of mobile was realised and characterised by France Telecom in the RNRT project ERMITAGES [15].
Base station antenna radiation pattern was simulated thanks to the SR3D software, the mobile antenna radiation pattern was measured in an anechoic chamber.

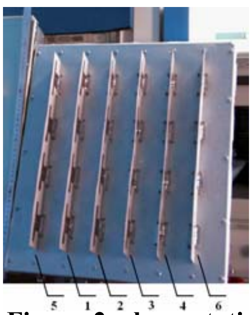

Figure 2 : base station antenna

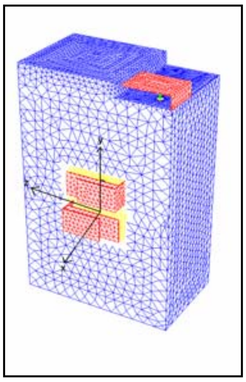

Figure 3 : mobile antenna (two PIFA)

We obtain space diversity for the base station antennas and diagram diversity for the mobile antennas.

To limit capacity computation time, we cancelled rays under a given dynamic, i.e. we consider only rays which have gain between the higher gain and the higher gain minus the chosen dynamic.
The ray dynamic is fixed at 20 dB. In these conditions, we keep 29 rays on average for each mobile position (*Table 1*). The dynamic choice results of an agreement between computation time and precision.

Ray dynamic	Average number of rays
5 dB	4
10 dB	8
15 dB	17
20 dB	29
25 dB	47
30 dB	70
35 dB	103
40 dB	148
45 dB	206
50 dB	272

Table 1 : Average number of rays obtained from the propagation model in function of the dynamic range

In the configuration considered here, the base station transmits and the mobile one receives. The transmission antenna is placed at 47 metres above the ground, the reception antenna at 1,60 metres above the ground in the centre of Paris (France). The working frequency is 2 GHz. 58 mobile macro positions uniformly spread in sector with a 90° angle and a 3 kilometres radius from the base station as shown in *Figure 4* were studied. The angle sector was chosen in accordance with the 3dB radiation pattern aperture for each of the 58 macro positions. We realised a local statistic by changing the azimuth angle at the mobile from 0° to 360°, and moving mobile over 20λ along x and y axis by 3λ step (*Figure 5*). On this distance, the channel is considered as stationary. The same rays are used to make a local statistic (the channel is supposed to be stationary on this distance) but they are calculated anew for another macro position.

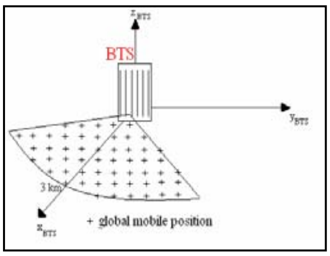

Figure 4 : global statistic

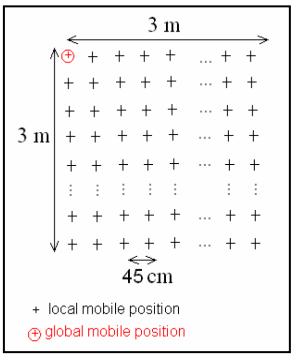

Figure 5 : local statistic

The H matrix is calculated by taking into account the antenna radiation pattern and thanks to the gain, the directions of departure, and the directions of arrival of each ray given by the model GRIMM.

4. Simulation results

The MIMO capacity is derived using the relation (1) for every point that is to say 588 local points at the 58 macro positions, for a total of 34 104 capacity values.

First, we use dipole array at transmission and PIFA antenna at reception (*Figure 6*). For the MIMO systems, we look two cases :

- one with transmission on the columns 1 and 2 (Nt=2, Nr=2)
- one with the transmission on the columns 1 and 4 (Nt=2, Nr=2 (div)).

In the second case, there is more space diversity at the base station (*Figure 2*).

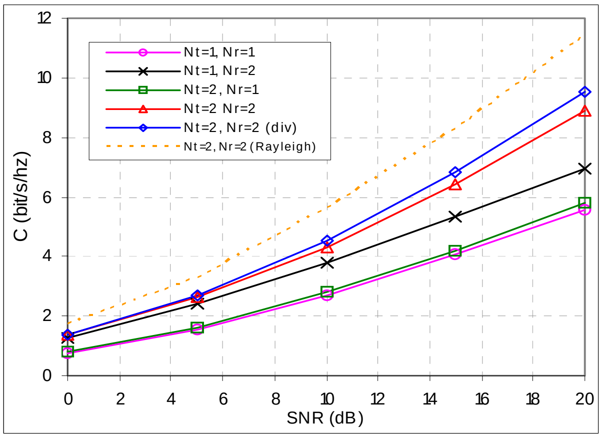

Figure 6 : Ergodic capacity for different real MIMO antenna configurations.

MISO (Multiple Input Single Output) and SISO capacity are about equals. At the transmission, we have a low space diversity because the transmit elements (columns 1 and 2) are very close. Adding space diversity at the transmission (columns 1 and 4) increases the capacity a little. Nevertheless, the capacity does not double when the number of transmit and receive elements double (C_{MIMO}=1.7*C_{SISO} at 20 dB of SNR) and the efficiency is far from the Rayleigh channel.

In order to check the validity of the MIMO hypothesis with actual antenna arrays and realistic channel provided by a ray model, we introduce arbitrary space diversity at the base station and at the mobile one. At the base station, the columns 1 and 2 are numerically moved 5 metres away from one another, and the PIFA antennas are moved 0.1 metre apart on the same way. The radiation patterns still unchanged.

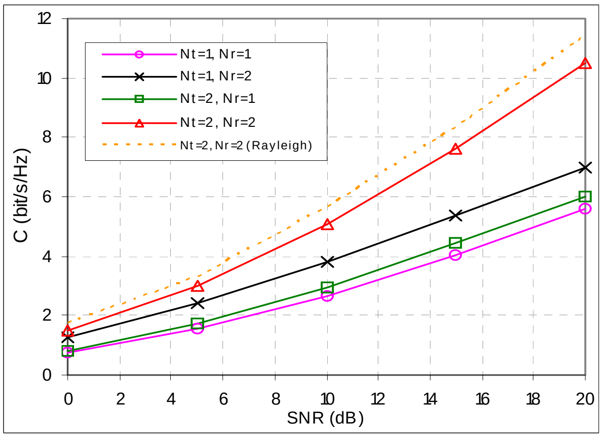

Figure 7 : Ergodic capacity for various real MIMO antenna configurations with de=5m and dr=10m.

Thanks to this new space diversity in transmission and reception, MIMO capacity almost increases (*Figure 7*) in 1.6 dB for a 20 dB SNR in comparison with a system having low diversity (*Figure 6*). Moreover, space diversity addition enables to approach the theoretical Rayleigh channel capacity.

At last, we study the MIMO capacity for a given mobile position with a 10 dB SNR according to the azimuth angle at the mobile station with original antennas configuration. The antennas are directive, then the mobile orientation strongly influence capacity value. *Figure 8* corresponds with a NLOS (Non Line of Sight) situation. The mobile user turn round but does not move.

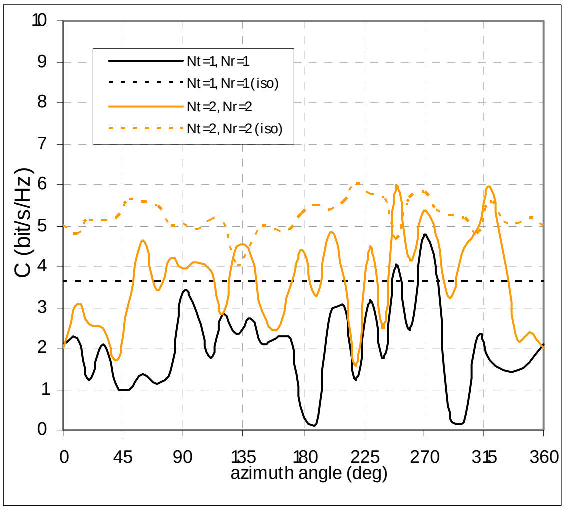

Figure 8 : capacity for a mobile position for SISO and MIMO configurations with isotropic or directional mobile antenna.

In case "iso", we use dipole arrays at transmission and isotropic antennas at reception.

By increasing antenna number in transmission and reception, we avoid reception hole. For example, for a 190° angle, capacity is almost zero for a SISO system. On the other hand, for the same orientation, the capacity of MIMO systems is 20 times higher. Moreover, we note that the isotropic antennas in reception provide a higher capacity average.

5. Conclusion

Simulation chain presented in this paper enables to estimate MIMO capacity in a realistic way according to transmission and reception antennas characteristics in cellular environment. The results reveal the essential part of the antennas in the capacity estimation. It has been shown that using this type of antennas, the capacity does not double when the number of transmission and reception antennas double, even introducing large space diversity. We have also pointed out that isotropic antennas in reception provide higher capacity than directives antennas. Therefore, antennas design must present diversity (spatial, diversity, pattern diversity or polarisation diversity) in transmission and reception and, reception antennas must be as more isotropic as it is possible to have maximal capacity.

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