MIMO Capacity Estimation at 2 GHz with a Ray Model in Urban Cellular Environment

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Abstract. *MIMO technology promises a linear increase of capacity in function of the minimum antenna number at the transmitter and at the receiver. In order to test if these performances can be actually met in mobile communications, we propose here a study of MIMO (Multiple Input Multiple Output) capacity in urban cellular environment at 2 GHz with a help of an efficient ray propagation model. We have tested different types of base station antennas (vertically or ±45° polarized) and two different types of mobile. Capacity is found to significantly increase between SISO (Single Input Single Output) and MIMO systems, but less than usually expected. We show that return and coupling losses as low as 10% can also reduce significantly the capacity. On the other hand, we study the influence of the way to take into account received power level on the MIMO capacity estimation.*

Keywords

Capacity, cellular environment, diversity, directivity, losses, multiple antennas.

1. Introduction

With the increase of multimedia services, mobile communications require higher and higher bit rate. Based on the use of transmission and reception antenna arrays, 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 data 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 information transfer rate without errors (in bit/s/Hz), increases linearly with the number of transmission and reception antennas.

Many studies are dedicated to the MIMO performances in different environments. These works are based on propagation models, such as ray models [2-4], geometrical models [5-8] or statistical models [1], [9], [10] or on measurement campaigns in indoor [11], [12] and outdoor [13], [14] environment. Here we propose a study of MIMO capacity in cellular urban environment at 2 GHz (UMTS band) by using GRIMM an efficient 3-D ray propagation model briefly described in Part 3. The conditions are also given in this section.

In Part 2, we describe multiple antennas for the transmitter (Tx) and the receiver (Rx) used in capacity estimation.

Usually, the noise level is set to a given threshold under the average signal received. We propose in Part 4 two methods to set this level and show their influence on the capacity estimation.

2. Antennas System

Characteristics of multiple antennas for base station and mobile phone are presented around 2 GHz for UMTS applications.

2.1 At the Base Station

At the base station (Fig. 1.), we use two types of antennas made of four parallel dipoles arranged in columns [15], [16]. Each antenna was characterized in an anechoic chamber in the UMTS band.

The first base station antenna (**b** in Fig. 1) is composed of six vertically polarized elements separated by 0.37 λ. The correlation coefficient between adjacent elements is rather high (0.5 at 2 GHz) but the coupling is always lower than –12 dB.

The S-parameters are:

$$\mathbf{S}_{VertPolar}(dB)=\begin{pmatrix} -8 & -12.5 & -19 & -25 \\ -12.5 & -8 & -12.5 & -20 \\ -19 & -12.5 & -8 & -13 \\ -25 & -20 & -13 & -8 \end{pmatrix} \qquad (1)$$

The second base station antenna (**a** on Fig. 1) is composed of four columns. Dipoles of one column are perpendicular to those of the next column. This antenna is ±45° polarized and the correlation coefficient is low (0.015 at 2 GHz). Return losses (S_{ii}) are lower than –24 dB and coupling losses (S_{ij}) lower than –23 dB:

$$\mathbf{S}_{DualPolar}(dB)=\begin{pmatrix} -30 & -26 & -26 & -26.5 \\ -26 & -25 & -33 & -23.5 \\ -26 & -33 & -24 & -28 \\ -26.5 & -23.5 & -28 & -25 \end{pmatrix}. \quad (2)$$

These two types of multiple base station antennas could be considered without losses because S-parameters are lower than –10 dB. They will be tested in cellular environment, the first type for its diagram diversity and the second type for its polarization diversity.

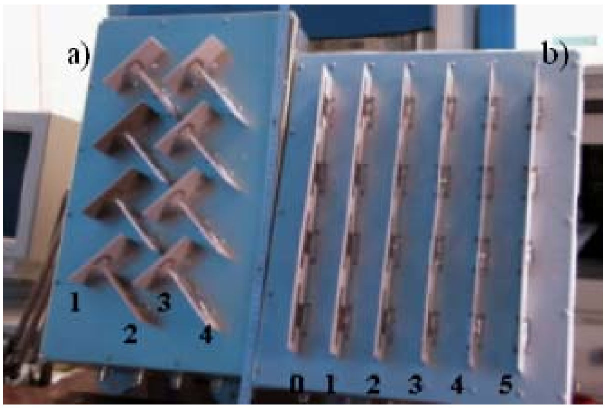

Fig. 1. Base station antennas: a) ±45° polarization, b) vertical polarization.

2.2 At the Mobile

The mobile antennas used in MIMO capacity simulation are made of two PIFA elements (Fig. 2.) [17].

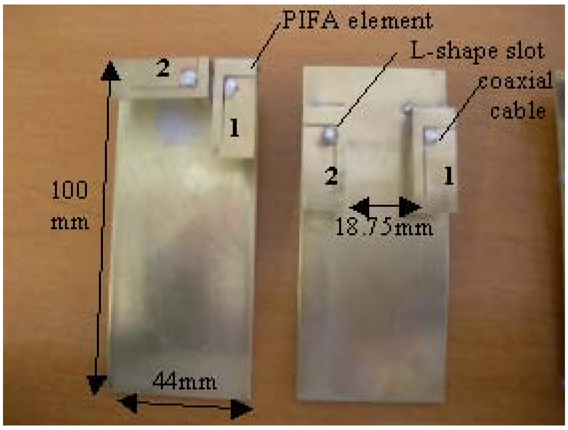

Fig. 2. Multiple mobile phone antennas (orthogonal configuration and parallel configuration).

In the first configuration, these elements are placed in parallel configuration. The optimal configuration of the elements was chosen to minimize the coupling between elements. The two PIFA elements were placed inside the limits of the ground plane, at 15 mm to the upper edge, to increase the isolation and the distance between them is 18.75 mm. Radiation patterns of the two elements are symmetrical. This antenna is vertically polarized and presents diagram diversity. The correlation coefficient is lower than 0.2. The S-parameters measured with a network analyzer (HP8510C) are:

$$\mathbf{S}_{Para}(dB)=\begin{pmatrix} -20.01 & -10.36 \\ -10.36 & -23.87 \end{pmatrix}. \quad (3)$$

In the second configuration, elements are placed in orthogonal configuration to provide polarization diversity conditions. For saving place, the orthogonal element was pushed up against the upper limit of the ground plane. In this way, the slot of the second element is against the side of the ground plane like the first element slot. The correlation coefficient is lower than 0.2 and the S-parameters are:

$$\mathbf{S}_{Ortho}(dB)=\begin{pmatrix} -10.62 & -11.4 \\ -11.4 & -8.32 \end{pmatrix}. \quad (4)$$

Return losses and coupling are lower than 10% for the two types of mobile antennas except for one element of the orthogonal configuration, which has return losses around 25%. These two mobile antennas present diagram diversity and look suitable for MIMO systems.

3. Data Processing

3.1 Propagation Model

We use the propagation model GRIMM [18], [19] developed by the CNET. This full 3-D model combines ray launching and ray tracing methods that allows a considerable reduction in computation times. The propagation channel modeling is made with geographical databases including information on external building structures. Phenomenons considered are reflections on building walls, horizontal and vertical diffractions, transmission through vegetation and buildings. This type of model allows the extraction of all the characteristics of the channel like the gain and the phase in the VV, VH, HV, HH polarizations, the elevation and the azimuth of each ray at the transmitter and at the receiver and the ray propagation time.

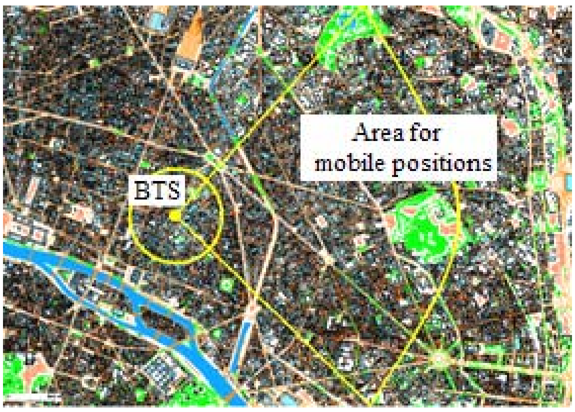

Fig. 3. Density of urban cellular environment (center of Paris – France). Simulation area with the model GRIMM.

For our simulations, the base station transmits and the mobile receives. The transmission antenna is placed at 47 meters above the ground, the reception antenna at 1.60 meters above the ground in the center of Paris (France) (Fig. 3.). The working frequency is 2 GHz.

3.2 Capacity Estimation

We considered a narrowband channel. Assuming no channel state information at the transmitter side, its capacity is given by [1]:

$$C = \log_2 \left[\det \left(\mathbf{I}_{NR} + \frac{\rho_s}{N_T} \mathbf{H}\mathbf{H}^H \right) \right] \tag{5}$$

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

4. Simulation Results

4.1 Influence of Antennas Characteristics

We have represented the capacity cumulative distributed functions (CDF) for 2x2 MIMO systems with antennas presented in Part 2. The Signal-to-Noise Ratio (SNR) is fixed at 10 dB. The capacity is estimated thanks to the base station and mobile antennas characteristics (radiation pattern and losses), the ray model GRIMM, and the relation (1). Simulation results were obtained in an urban cellular environment at 2 GHz with (Fig. 4.) and without (Fig. 5.) taking into account antennas losses at the mobile terminal.

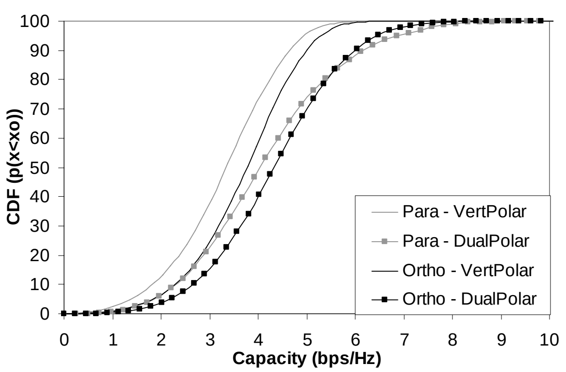

Fig. 4. Capacity CDF for 2x2 MIMO systems with different types of base station (vertical or dual polarized) and mobile (parallel or orthogonal configuration) antennas without loss.

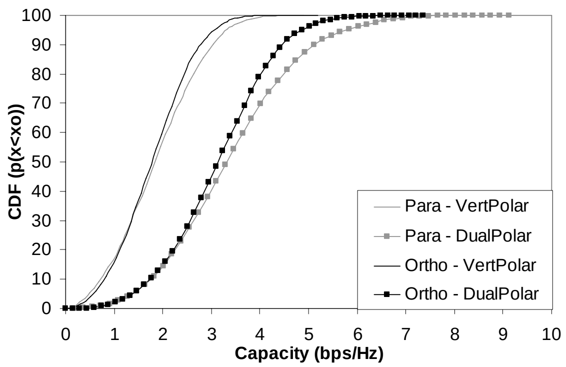

Fig. 5. Capacity CDF for 2x2 MIMO systems with different types of base station (vertical or dual polarized) and mobile (parallel or orthogonal configuration) antennas including losses.

Dual-polarized (±45°) base station antenna gives higher capacity values than the single polarized (vertical) one. In fact, base station vertically polarized is not well adapted to MIMO applications due to the closeness of its radiating elements (0.37 λ, i.e. 54 mm at 2 GHz) and its poor diagram diversity. The polarization diversity at the base station is much important to achieve the best capacity in cellular environment.

If we do not take into account return losses and coupling at the mobile, the best capacity is achieved by the orthogonal configuration of antenna with both types of base station. In fact, orthogonal elements present diagram diversity in the elevation and the parallel configuration diversity in azimuth. Moreover, in the orthogonal configuration, the second element radiates almost with the same directivity in the vertical and the horizontal plane whereas in the parallel configuration, the two elements radiate only in the vertical plane.

However, to obtain realistic results, we must take into account losses. In this case, capacity is between 17% and 44% lower according to the couple Tx-Rx in 50% of cases. If we include losses, the parallel configuration is better than the orthogonal configuration because the two radiating elements have losses lower than 10% whereas the orthogonal configuration has losses lower than 10% for only one of its radiating elements, the second one having losses around 25%.

4.2 Received Power Level

The paths number increases with the distance between the transmitter and the receiver while the power received decreases. In this fact, we can wonder if the diversity gain of the channel can compensate the received power decrease. We would have a data transfer rate much homogenous in the cell. Generally, propagation models (i.i.d. – Identically and Independently Distributed [1], Kronecker [9]) do not give the power level of the received signal or do not link it with the other channel parameters.

Fig. 6. represents the capacity cumulative distributed functions for SNR=10 dB at 2 GHz in urban cellular envi-

ronment. SISO and 2x2 MIMO systems use the vertical polarized base station antenna and the mobile antenna in parallel configuration. *Case 1* and *Case 2* depend of the power level estimation of the received signal.

Case 1:

Previously, we have chosen the mean capacity on the local positions for the noise.

In this case, the noise is different according to the global position of the mobile phone. It includes only the MIMO gain of the channel, i.e. the diversity gain due to the multi-paths. So, a directive antenna, which received sometimes a lot of power, other time nothing, gives good capacity values (in black in Fig. 6.). Minus 20% of capacity values are lower then 2 bps/Hz.

Case 2:

To take into account the total effective gain, i.e. the MIMO gain and the power gain, we propose to set the noise level in correspondence of the receive power average on the set of the macro positions (in grey in the Fig. 6.). Then, the noise threshold is constant whatever the mobile position. It is more realistic because the noise considered is a thermic noise and does not depend on the mobile position. In this case weak capacities are more numerous than in the previous case, where the noise was variable (more than 60% lower than 2 bps/Hz).

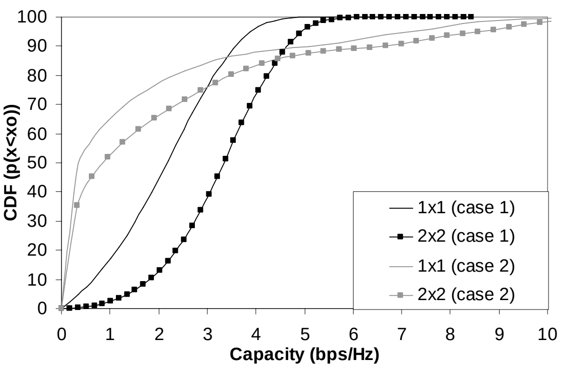

Fig. 6. Capacity CDF for SISO and 2x2 MIMO systems in function of the received power level.

The MIMO gain does not compensate the power loss and there is an increase of capacity differences between the weak points and the high points. Therefore, it is essential to take into account the received power gain not to bias the capacity estimation of a MIMO system.

If we compare SISO and MIMO systems, we can see a significant improvement in capacity. Nevertheless, this increase (50% in average) is lower than the expected with an i.i.d. Rayleigh model.

5. Conclusion

Our efficient 3-D ray propagation model has enabled to study the MIMO capacity performances in UMTS band. We have shown the importance of Tx-Rx antenna characteristics and the benefit of using dual polarization scheme in urban cellular environment. Moreover, we have studied the influence of received power level on MIMO performances. The results have shown that the MIMO gain due to the multi-paths propagation cannot compensate the power loss when the distance between the transmitter and the receiver increases.

It is essential to test MIMO performances with real antennas taking into account radiation patterns and losses in real conditions of propagation. Otherwise, the performances look much better but are not realistic.

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Sophie VERGERIO was born in 1980 in Nice (France). She received the MSc degree in microelectronic from the University of Provence and the engineering diploma from Polytech'Marseille School in 2004. She completed her PhD in Radiation and Plasma from the University of Aix-Marseille in July 2007. She worked for France Telecom R&D during more than 3 years on antenna optimal characteristics and capacity estimation for MIMO systems. Since October 2007, she is working on wireless networks in R&D department of EDF (Electricité de France).

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