

CHANNEL CAPACITY EVALUATION OF UMTS MULTI-ANTENNA SYSTEMS IN INDOOR AND OUTDOOR ENVIRONMENTS

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Abstract

This paper results from a collaborative work between the LEAT of the University of Nice and the Radio Laboratory of Helsinki University of Technology (TKK) in the framework of the DEMAS project of ACE2, the European antenna-center of excellence. The purpose is the channel capacity evaluation of different UMTS multi-antenna systems with high and low isolation in indoor and outdoor environments for MIMO purposes. The antennas have been designed at the LEAT and presented in previous papers. The evaluation of the channel capacity has been done with a practical tool called measurement-based antenna test bed (MEBAT) which is presented by TKK in several papers.

1 Introduction

Nowadays, the use of wireless mobile communications is growing exponentially in several fields of telecommunications. Transferring large amounts of data is clearly needed and consequently, increasing the transfer rate is more and more required. The performances of a wireless terminal can be greatly improved by introducing some diversity scheme in the communication link. In practice, the handset can be considered to operate in a so-called multipath propagation environment. This means that the electromagnetic field which carrying the information will take many simultaneous paths between the transmitter and the receiver. To take advantage of this propagation scenario, one solution is to integrate more than one radiating element in the terminal but also at the base station to generate several communication channels (Multiple-Input-Multiple-Output (MIMO) system). The antennas of the handset must therefore be properly designed, the most relevant parameters being the envelope correlation, the total efficiency, the diversity gain to get an enhanced channel capacity. Some multi-antenna structures have been designed, fabricated and measured at the LEAT of the University of Nice [1]. Particularly, a neutralization effect implemented between two Planar Inverted-F Antennas (PIFAs) operating on a small ground

plane in close frequency bands has been demonstrated to achieve high isolation and high total efficiency [2]. However, their fully characterization in urban or indoor conditions (uniform multi-path propagation environment or Rayleigh fading) needs some particular facilities and the associated expertise. Thus, this paper results from a collaborative work between the LEAT of the University of Nice and the Radio Laboratory of Helsinki University of Technology (TKK) in the framework of the DEMAS project of ACE2, the European antenna-center of excellence. The purpose is the channel capacity evaluation of two-antenna systems and four-antenna systems operating in the UMTS band with high and low isolation in indoor (picocell) and outdoor (microcell and macrocell) environments for MIMO purposes. The evaluation of the channel capacity has been done with a practical tool called measurement-based antenna test bed (MEBAT) [3].

2 Multi-antenna-systems

The optimized two-antenna system consists of two antennas linked by a neutralisation line inserted between their feeding strips (Fig. 1) to enhance their isolation [2]. The maximum S_{21} is smaller than -20 dB at 2 GHz. The improvement in regards to the reference system (two-antenna system without any neutralization line) is 12 dB at this frequency (Fig. 2). The simulated total efficiencies are 81% for the reference system and 94% for the neutralized system. We see that an increase of the isolation leads to an enhancement of the total efficiencies.

The same principle was used to design a neutralized four-antenna system (Fig. 3) where the top two antennas are linked by their feeding strips and the two others by their shorting strips [2]. The scattering parameters can be seen in Fig. 4. All the isolations between the elements are higher than -15 dB. Here again, increasing the isolation between the elements, allows to improve their total efficiencies. Indeed the total efficiency of the elements of the system are 94% for the upper antennas and 91% for the two others.

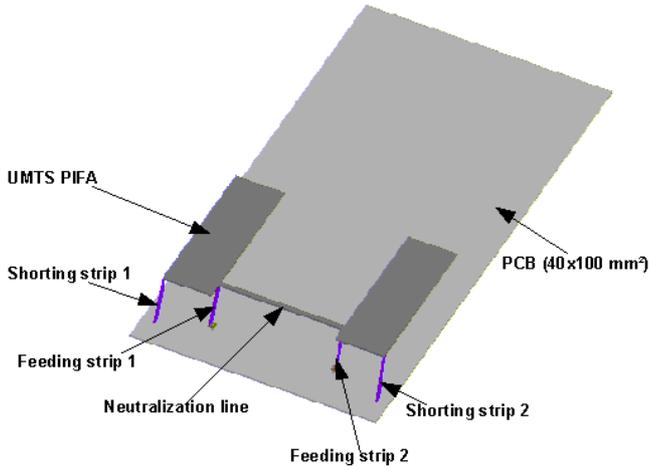


Fig. 1: 3D View of the two-antennas neutralized system

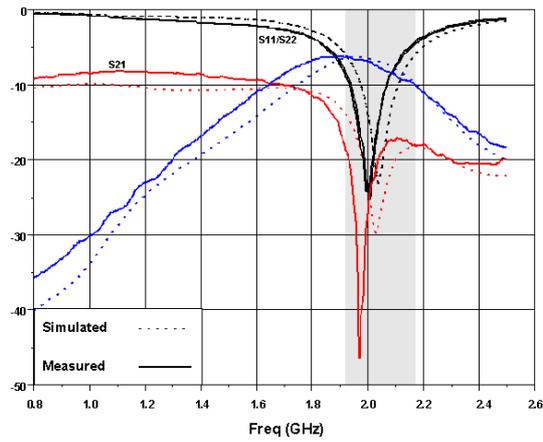


Fig. 2: S_{ij} parameters of the neutralized two-antenna system (red) and S_{21} of the reference two-antenna system (blue)

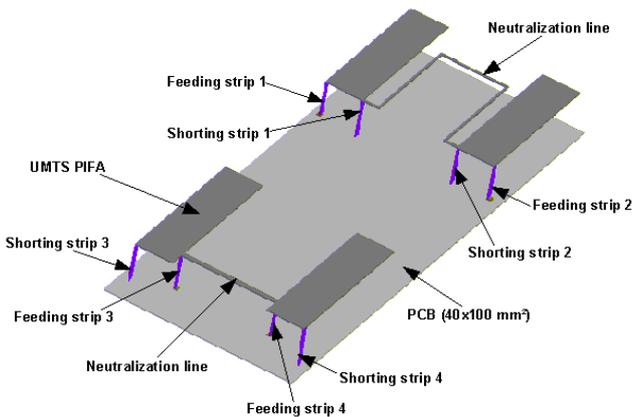


Fig. 3: 3D View of the neutralized four-antenna system

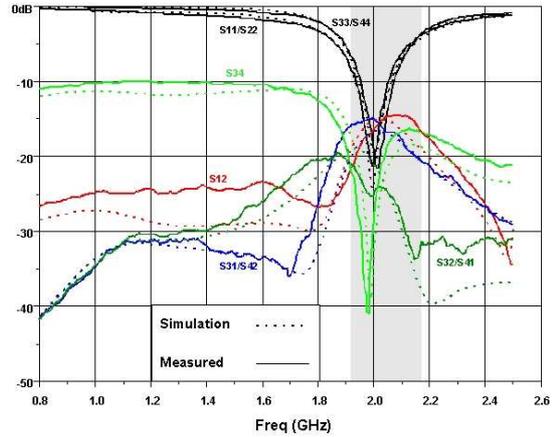


Fig. 4: S_{ij} parameters of the neutralized four-antenna system

Then the MIMO performance of these optimized systems has been evaluated in real multipath environments and compared with the one of the reference systems. The purpose is to show the improvement of the channel capacity brought by the increase of the isolation between the radiating elements. These measurements have been done with the practical tool called measurement-based antenna test bed (MEBAT).

3 MIMO MEBAT analysis

3.1 MEBAT tool

In the MIMO MEBAT analysis, different antenna prototypes as well as a reference antenna with cross-polarized dipoles were analyzed in different signal propagation routes. At the Tx end of the link, two dual-polarized patch antennas were selected out of the linear and zigzag antenna arrays of 16 elements (Fig. 5 and 6) for the two-antenna system (one polarization for each antenna). Four dual-polarized patch antennas were selected out of the linear and zigzag antenna arrays of 16 elements for the four-antenna system (one polarization for each antenna). A single antenna element of the arrays is illustrated in Fig. 7. Inter-element distance between the elements of the array was in the cases of the zigzag and the linear array 4.2λ and 3λ , respectively.

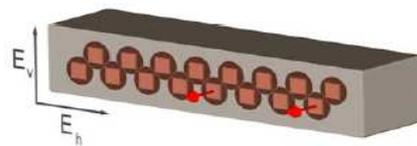


Fig. 5: Zigzag antenna array with distance of 0.5λ between the elements.

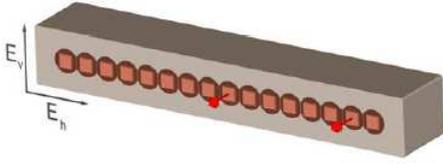


Fig. 6: Linear antenna array with distance of 0.7λ between the elements.

The linear Tx antenna array was used in indoors and the zigzag Tx antenna array in outdoors. The routes analyzed consisted of picocell (indoor), microcell (outdoor) and small macrocell (outdoor) [3] [4] [5].

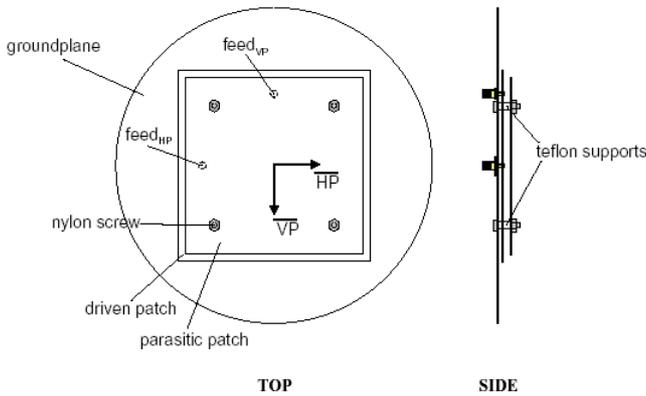


Fig. 7: Single element of the linear and zigzag antenna arrays

The analysis was made for three different signal propagation environments. The picocell (indoor) measurement was carried out in Computer Science building of TKK (Route 8 in Fig. 3). At the base station, the linear Tx antenna array was used in the analysis. 1717 samples were taken all along the 60 m route. The height of the space station (FS) was 3.8 m and the height of the Rx (spherical antenna mounted on the trolley) about 1.5 m.

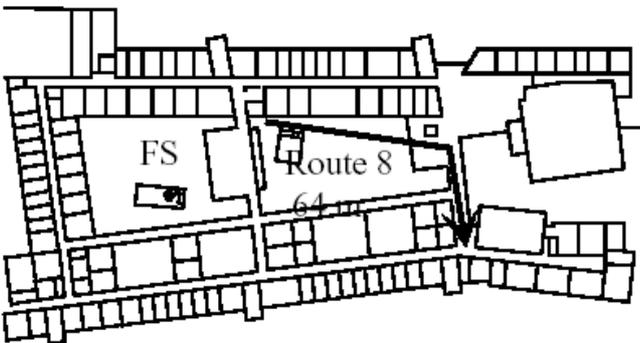


Fig. 8: Picocell (indoor) route

The microcell (outdoor) route was measured in Helsinki downtown. The number of the samples were 2500 over 87 m, the height of the Tx antenna (FS) was 13 m and the height of the Rx (spherical antenna mounted on the trolley) about 1.5

m. The position of the base station elevated by the crane is marked by the arrow FS in Fig. 9. At the base station the zigzag Tx array was used.

The small macrocell (outdoor) route was measured in Helsinki downtown, route 1 in Fig. 10 was selected for the analysis. The Zigzag Tx antenna array was used in this analysis. The length of the route was 47m and 1342 samples were taken along this length. The space station (FS) was located above the rooftops and the height of the Rx (spherical antenna mounted on the trolley) was about 1.5 m.

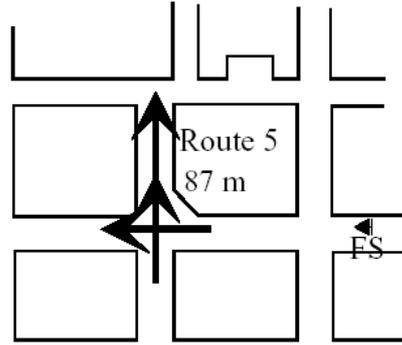


Fig. 9: Microcell (outdoor) route

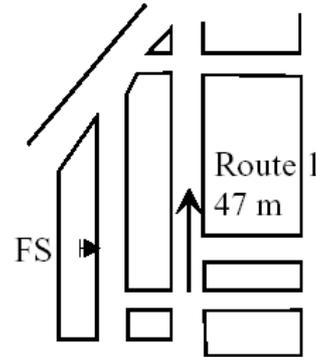


Fig. 10: Small macrocell (outdoor) route

3.2 Evaluation of the capacity performance

Generally, in real measurements of the dynamic channel, the signal contains both slow and fast fading. Thus, the distribution of the received signal can be totally different if the effect of slow fading is included, or alternatively excluded. Hence, for removing a slow fading from such a result, a sliding mean over the received power of the antennas for normalization should be taken (Equation (1), [5]).

$$\|H_{norm, sl}^{(i)}\|_F^2 = \frac{1}{2N+1} \sum_{i-N}^{i+N} \|H_{norm}^{(i)}\|_F^2 \quad (1)$$

where $2N+1$ is the number of samples in the sliding window. Usually, a sliding window of 100 samples ($2N+1 = 100$) is used in the calculations.

Secondly the received power of the prototype antennas should be normalized (divided) with the normalization power (see Equation (2))

$$H(i)H(i)^H = \frac{H_{aut}^{(i)} H_{aut}^{(i)H}}{\frac{1}{n_t n_r} \|H_{norm, sl}^{(i)}\|_F^2} \quad (2)$$

where n_t and n_r are the numbers of the transmitter and receiver antennas respectively, and i goes over the samples of the channel. The expressions $H_{aut}^{(i)}$ and $H_{norm}^{(i)}$ denotes the channel matrices for prototype antennas (H_{narrow}) and for normalization (isotropic) antennas (H_{narrow_norm}), respectively. The expression $\|\cdot\|_F$ is the Frobenius norm and H denotes the Hermitian transpose. Thus the MIMO capacity channel is defined by Equation (3) where ρ is the signal to noise ratio.

$$C = \log_2 \left(\det \left[I_N + \frac{\rho}{n_t} H_{aut}^{(i)} H^{(i)H} \right] \right) \quad (3)$$

In addition, all the antenna-systems were rotated in the environment for six different orientations in azimuth with 60° degrees step to guarantee a statistically sufficient analysis. Thus, the mean capacity of all the prototypes in the different environments are calculated and presented here. The measured mean capacity of the two-antenna system is presented in Figure 11, 12, 13. The cumulative distribution function (cdf) which is the probability that the mean capacity is smaller than a certain threshold is presented in Figure 14.

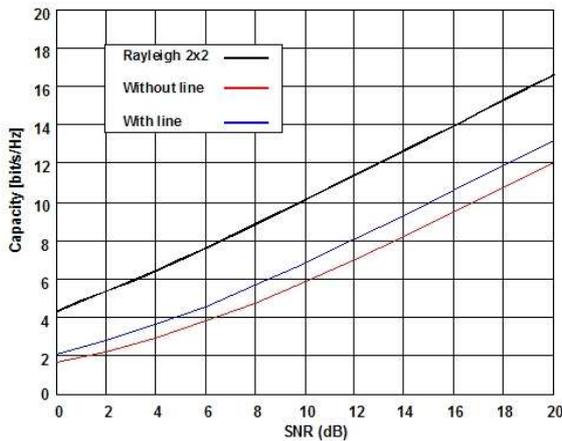


Fig. 11: Capacity of the two-antenna systems as a function of SNR at 2 GHz (picocell environment)

First, we can see that the mean capacity is better in picocell and smaller macrocell environments than in the microcell environment. This difference is between 0.5 and 1 bps/Hz for each prototype. This is due to the reflection of the waves which is more important in a indoor or small macrocell outdoor that in microcell outdoor environment. When we

compared the neutralized two-antenna system to the reference system, we can see that the enhancement of the mean capacity is quite the same in all the environments: 1 bps/Hz for reasonable SNR. This is due to the increased isolation which enhance the total efficiency of the antennas of the structure. However, this improvement is not impressive regarding the total efficiency improvement seen for the antennas.

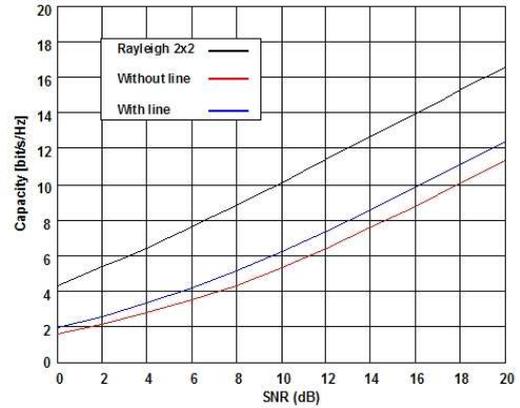


Fig. 12: Capacity of the two-antenna systems as a function of SNR at 2 GHz (microcell environment)

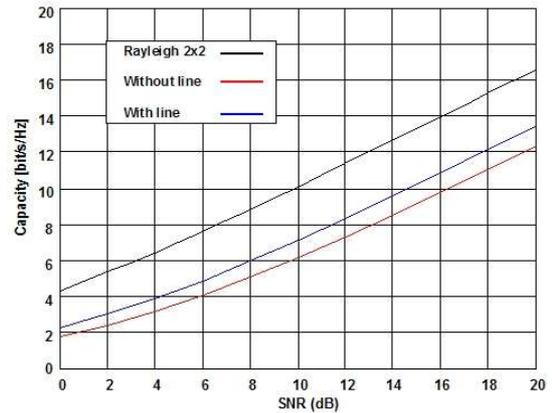


Fig. 13: Capacity of the two-antenna systems as a function of SNR at 2 GHz (small macrocell environment)

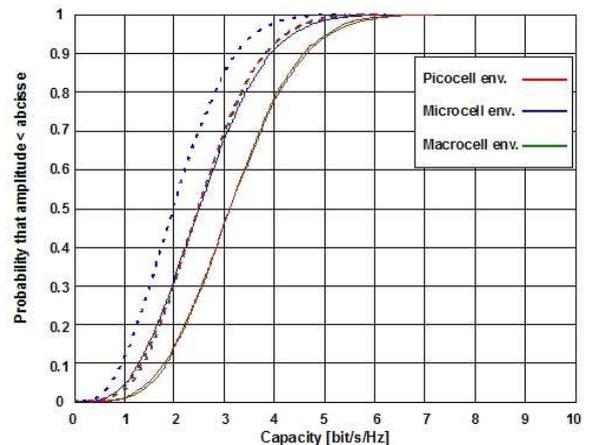


Fig. 14: Capacity of the neutralized two-antenna systems (plain line) and the reference two-antenna system (dashed line) in different environments at 2 GHz for a SNR=10 dB

In MIMO systems, when we increase the number of antennas in the reception system, the capacity should increase too. Thus, the mean capacity of the four-antennas system is evaluated in a picocell and a microcell environment and compared with a reference four-antenna system with a lower isolation between the radiating elements. The simulated total efficiency of the elements of the reference system is around 70%. The mean capacity of these systems is presented in Figure 15 and 16 and the probability that this capacity is smaller than the threshold value for a SNR = 10 dB is presented in Figure 17. The mean capacity in indoor environment (picocell) is slightly better than the mean capacity in outdoor environments (0.5 bps/Hz). When we compare both four-antenna systems, we can see that the neutralized prototypes are only improving the capacity by 1 bps/Hz. This improvement is the same in picocell and in microcell environments (Fig. 15 and 16). In Figure 17, the cdf curve is clearly showing that the probability to have the mean capacity below a certain threshold is always better with the neutralized system.

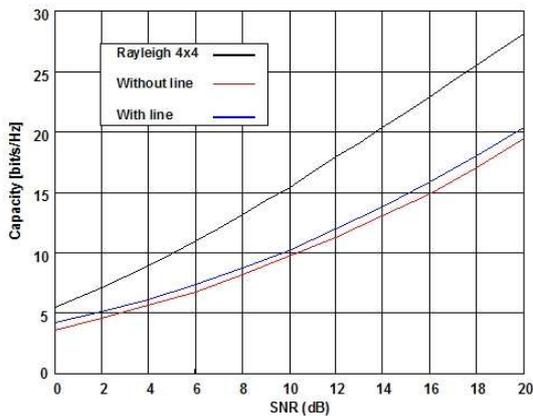


Fig. 15: Capacity of the four-antenna systems as a function of SNR at 2 GHz (picocell environment)

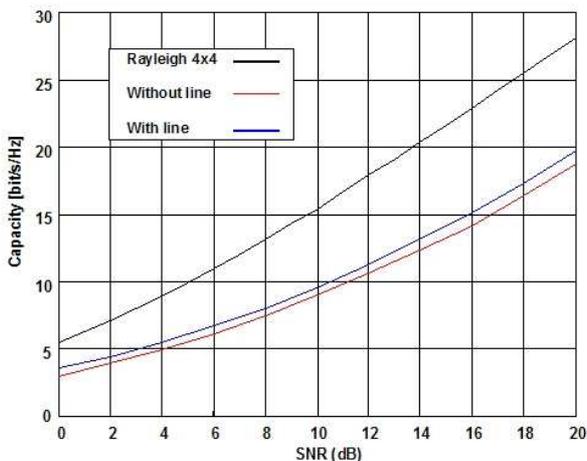


Fig. 16: Capacity of the four-antenna systems as a function of SNR at 2 GHz (microcell environment)

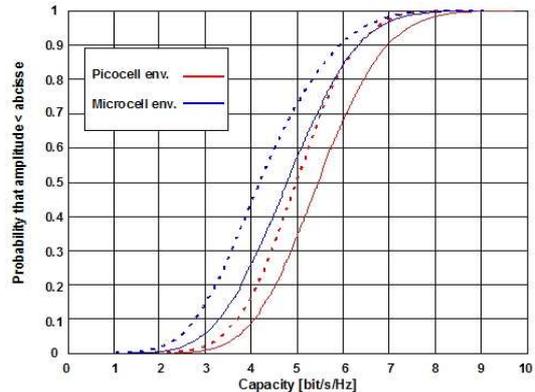


Fig. 17: Capacity of the neutralized four-antenna systems (plain line) and the reference four-antenna system (dashed line) in different environments at 2 GHz (SNR=10 dB)

3 Conclusion

In this paper, the evaluation of the channel capacity of different multi-antennas systems in indoor, small macrocell and microcell environments was presented. This evaluation has been done with a practical tool called MEBAT (designed by TKK of Helsinki). First the mean capacity of a two-antenna system with high isolation was measured in the three environments and compared with the one of a two reference system with low isolation. The enhancement is just 1 bps/Hz while the isolation improvement is more than 10 dB. The same kind of improvement was found for neutralized four-antenna prototype versus reference prototype. It is also shown that the channel capacity is better in indoor or small macrocell environment than in a microcell environment.

References

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