



**HAL**  
open science

## Effect of propagation phenomena on MIMO capacity of wireless systems between 3 and 10GHz

Nadine Malhouroux-Gaffet, Patrice Pajusco, Edgard Haddad

► **To cite this version:**

Nadine Malhouroux-Gaffet, Patrice Pajusco, Edgard Haddad. Effect of propagation phenomena on MIMO capacity of wireless systems between 3 and 10GHz. EuCAP 2010: European Conference Antennas and Propagation, Apr 2010, Barcelona, Spain. hal-00527597

**HAL Id: hal-00527597**

**<https://hal.science/hal-00527597v1>**

Submitted on 18 Jul 2018

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Effect of propagation phenomena on MIMO capacity of wireless systems between 3 and 10 GHz

Nadine Malhouroux-Gaffet<sup>#</sup>, Patrice Pajusco<sup>+</sup> and Edgard Haddad<sup>#</sup>

<sup>#</sup> Orange Labs, 6 av. des usines, 90007 Belfort Cedex

nadine.malhouroux@orange-ftgroup.com

<sup>+</sup>Télécom Bretagne, Lab-STICC, CS 83818, 29238 Brest, France

patrice.pajusco@telecom-bretagne.eu

**Abstract**— Multiple Input Multiple Output (MIMO) Antenna systems promise high spectral efficiency [1] over multipath channels. But accurate wideband MIMO channels models are required to optimize these new radio access schemes. This paper focuses on the MIMO channel capacity versus different propagation channel parameters such as frequency or antenna type. This study is based on both experimental and simulated results in a residential environment. The simulations have been computed with a full 3D ray tracing tool while measurements have been performed with a UWB MIMO channel sounder.

## I. INTRODUCTION

Increasing the system capacity is a constant goal in the mobile communication research area. The promising MIMO technology is still instigating a large of work especially on propagation study. The potential capacity of a wireless system is indeed directly related to the space-time characteristics of the propagation channel. For the last 10 years, efficient channel sounders have been designed. This equipment requires two antenna arrays to estimate directions of departure and arrival at the transmitter and the receiver respectively. Uniform linear arrays (ULA), uniform planar arrays (UPA) or uniform circular arrays (UCA) are often used. However, all of these arrays have drawbacks which can lead to major biases on the estimate of space-time characteristics [1]. Thus, a comprehensive space-time characterization of the UWB propagation channel is usually not investigated because a complex measurement setup is required. In the first paragraph, this study presents a simple setup which enables the estimation of the full 3D space-time characterization including frequency dependence.

The second part presents a Ray tracing tool "Matrix" that has been optimized with the measurement carried out with the MIMO UWB experiment presented above. The study of the MIMO capacity behaviour in function of the frequency, the antenna pattern, the numbers of reflection, transmission, and diffraction has been completed with the simulated channel. Simulated data allows analysing all these parameters independently. MIMO channel modelling and the MIMO capacity definition based on the singular value decomposition are presented in the third part.

MIMO capacity variations are analysed in function of several parameters as the antenna pattern, the frequency of simulation, the simulation configuration. A final section

presents a comparison between simulated and measured MIMO capacities.

## II. MIMO UWB EXPERIMENT

### A. Description of the Experimental Set-up

Characterizing the propagation channel is the first step toward the development of accurate propagation models. For this purpose, a new UWB experimentation allowing full 3D space-time characterization has been set up [3]. The MIMO UWB channel sounder is based on two uniform circular arrays (UCA). One is located at the transmitter and the other at the receiver. Each UCA is built with 5 UWB antennas orthogonally mounted to each other. These UWB sensors present a pattern frequency dependence shown in Fig. 1 and a picture of the 5-axis antennas is depicted on Fig. 2.

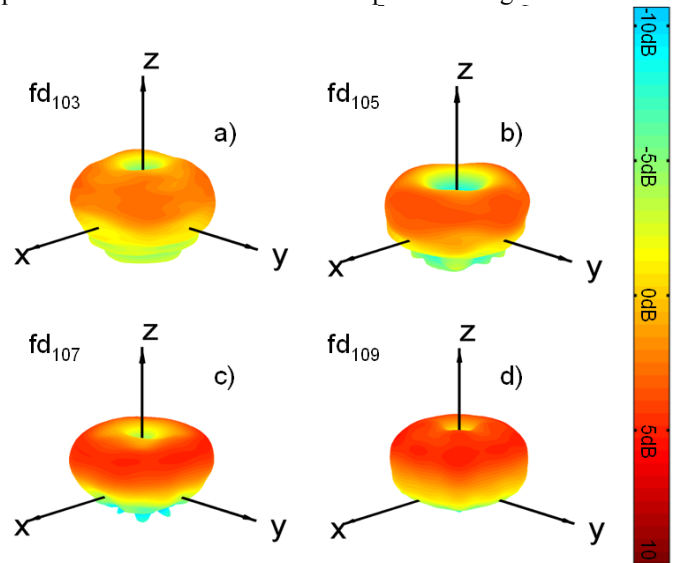


Fig. 1 UWB sensor farfield pattern in vertical polarization at a-3, b-5, c-7, d-9 GHz.

The transmission channel was estimated with a vector network analyser (VNA). Two LNAs were used to improve the link budget. The measurement is fully automated with Matlab software. The synoptic of the UWB MIMO channel equipment are depicted in Fig. 3. The MIMO configuration consists of measuring all the links between all the transmitting

antennas toward all the receiving antennas for each possible location.

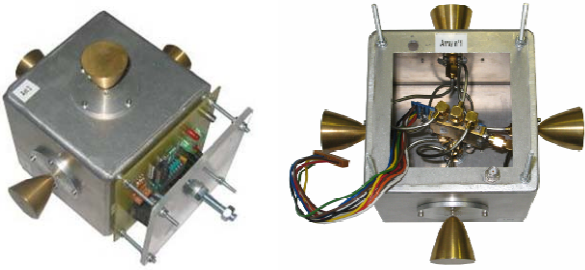


Fig. 2 5-axis antenna array

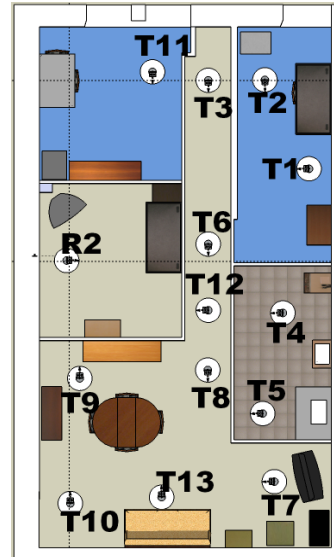


Fig. 4 Virtual uniform circular array and measurement locations in the residential flat.

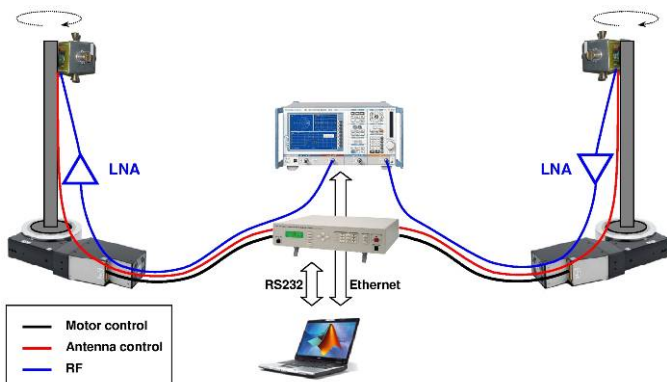


Fig. 3 MIMO UWB measurement setup.

### B. Environment and Measurement Campaign

The measurement campaign has been carried out in a typical flat built inside the Orange labs premises. The measurement locations are shown in Fig. 4. Thirteen transmitter positions have been chosen to have different radio link configurations for the characterization of the propagation modelling. The direct path between the transmitter and the receiver ranged from 3 to 8 meters and crossed different architecture elements like plasterboard walls, bearing board walls, doors and some furniture.

## III. PROPAGATION CHANNEL SIMULATION

### A. Ray Tracing Simulation Parameters

The simulations have been performed with a 3D ray tracing software "MATRIX" based on geometrical optics (GO) and the uniform geometrical theory of diffraction (UTD).

The ray tracing algorithm has been optimized on the whole UWB bandwidth, taking into account dielectric material coefficients previously determined for a large frequency band (2-12 GHz) [2]. Different combinations of the propagation phenomena are taken into account (Reflection, transmission, diffraction).

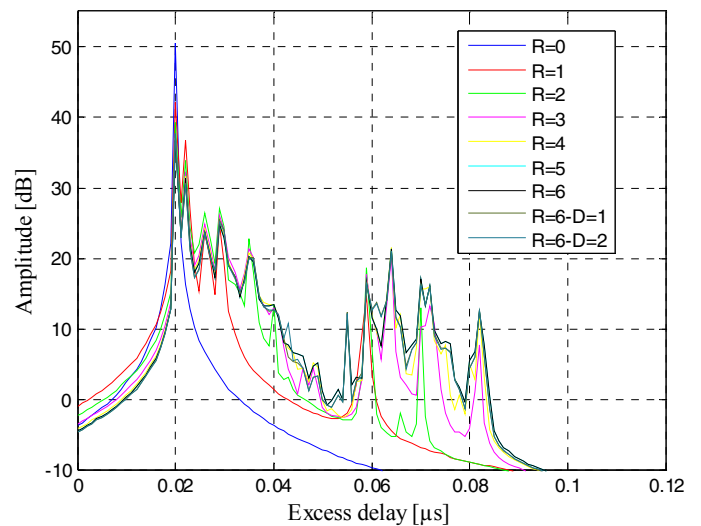


Fig. 5: Simulated normalized Power Delay Profile at 5 GHz for the link T2R2 for different propagation phenomena.

The simulations are performed in a residential environment described by the properties (dimensions, thickness, permittivity, conductivity) of all architectural elements (walls, floor, ceiling, doors, and windows) and the furniture of each room. The computed ray paths are characterized by their  $2 \times 2$  complex gain, delay, direction of arrival (DoA), direction of departure (DoD). One example of the Power delay Profile is depicted on Fig. 5. The 100 strongest rays have been taken for the computation of the impulse response.

In order to integrate the antenna pattern in the simulations, each element of the 5-axis antenna has been measured in each azimuth and elevation angles in the two polarizations for frequencies from 2 to 16 GHz.

## IV. MIMO CAPACITY ESTIMATION

### A. Definition

A MIMO system uses several transmitter antennas ( $n_T$ ) and several receiver antennas ( $n_R$ ). The received signal  $y$  at the antenna  $i$  ( $i=1, \dots, n_R$ ) is the sum of the transmitted signals  $\{s_1, \dots, s_n\}$  multiplied by the complex gain  $h_{ij}$  of the corresponding radio links and the noise  $n$ :

$$y_i = \sum_{j=1}^{n_T} h_{ij} s_j + n_i \quad y = \mathbf{H} s + \mathbf{n}$$

$$\mathbf{H} = \begin{pmatrix} h_{11} & \dots & h_{1n_T} \\ \vdots & \ddots & \vdots \\ h_{n_R 1} & \dots & h_{n_R n_T} \end{pmatrix}$$

$n_i$  is the equivalent baseband noise whose elements are considered as zero mean circular-symmetric complex additive Gaussian noise (AWGN) samples with a variance of  $\sigma^2$ .  $\mathbf{H}$  can be decomposed in singular values:

$$\mathbf{H} = \mathbf{U} \mathbf{\Sigma} \mathbf{V}^H \quad \text{with} \quad \mathbf{\Sigma} = \text{diag} \{ \lambda_i \}_{i=1}^b$$

If the transmitter has no channel state information, the simplest way for power allotment is to distribute the available power equally over the  $n_T$  antennas. In this case, the capacity is given by:

$$C = \sum_{i=1}^{\min(n_T, n_R)} \log_2 \left( 1 + \frac{\rho}{n_T} \lambda_i \right)$$

### B. Computation of the MIMO Capacity

The MIMO-UWB experiment described above corresponds to a virtual  $180 \times 180$  sensors array. The geometry of the array is circular. This experimentation allows an extraction of sub-arrays of different sizes, spacing, geometry and numbers of sensors. For instance, four successive antennas can be considered as a small uniform linear array. Hence many configurations can be considered. An average capacity can be estimated by averaging the sub-arrays capacities. This provides a representative estimate of the local channel capacity and this, for different sub-array configurations.

In order to take into account the path loss, the computation of the capacity is realized with a normalized channel power transfer function. The Frobenius norm was used. The normalised MIMO channel matrix is given by:

$$\mathbf{H}_{norm} = \frac{\mathbf{H}}{\sqrt{\frac{1}{n_T n_R} \sum_{i,j} |h_{ij}|^2}}$$

## V. RESULTS ANALYSIS

### A. Effect of Propagation Phenomena on the Capacity

A previous investigation based on measurement has been carried out in order to analyse the number of reflections,

transmissions and diffractions required to characterize the propagation channel. The result of this study shows wideband parameter stabilization in our environment for a given number of phenomena: 10 transmissions, 6 reflections, 2 diffractions. The channel capacity was computed with these different simulation configurations. The results show a capacity increase of more than 30 bps/Hz between the simulations. In agreement with the power delay profile behaviour (Fig. 5), the capacity value has almost no variation between the configurations with 10 transmissions, 6 reflections and 1 or 2 diffractions.

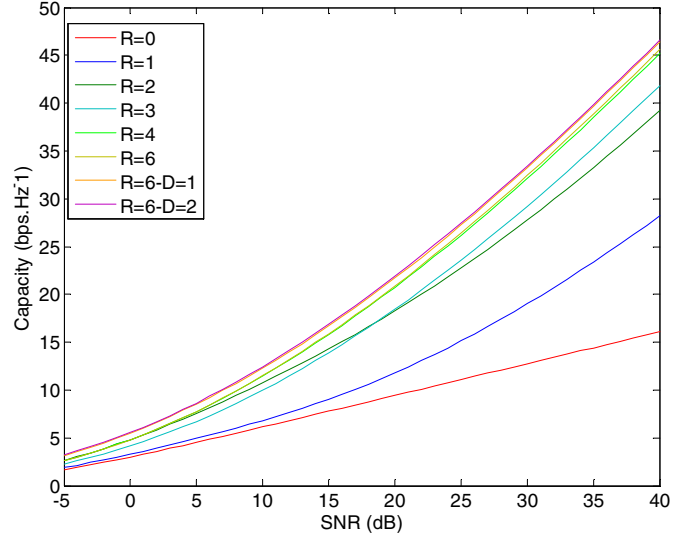


Fig. 6 Mean capacity versus SNR at for a  $7 \times 7$  array according to the number of propagation (R: Reflection, D: diffraction, 10 Transmissions) phenomena or an isotropic antenna diagram

### B. Antenna Pattern Effect on Capacity

Some studies have reported the effect of antenna pattern [4] on the estimation of the capacity and suggested to design antennas according to the environment. In an UWB configuration, the antenna pattern depends on the frequency band. Hence, the influence of the antenna pattern on the channel capacity has to be investigated. Ray tracing simulations are very convenient because they allow the decorrelation of the antenna pattern and the propagation channel. So, with a set of rays representing a MIMO link, the estimation of the capacity can be computed with different antenna patterns. The results depicted in figure 7 correspond to the T2-R2 radio link. The simulation is performed at 5 GHz but used different antenna diagrams ( $fd_{103}, fd_{105}, fd_{107}, fd_{109}$ ) corresponding to the patterns of the UWB antenna at respectively the frequencies: 3, 5, 7, 9 GHz. In order to compare only the effect of the antenna pattern, the same normalising factor was applied to all simulations.

A maximal difference of 15 bps/Hz is obtained between the pattern  $fd_{103}$  and  $fd_{105}$ . The variation is not linear according to the pattern frequencies. This could be explained by the change of aperture in function of the frequency that leads to a change of integrated rays to the MIMO matrix computation.

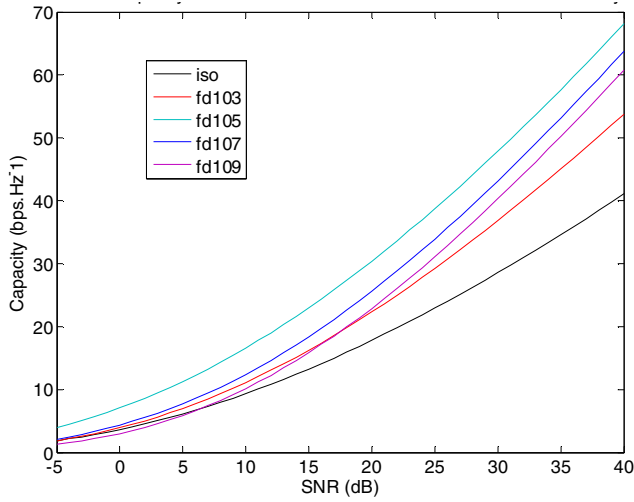


Fig. 7 Mean capacity at 5 GHz versus SNR of a  $7 \times 7$  array (spacing= 2cm) in function of antenna pattern.

### C. Effect of the Frequency on Capacity

Experimental analysis of the impact of the frequency has been investigated in [5]. These results reported a frequency dependence of the capacity but the influence of the antenna pattern has not been considered. To avoid this effect, ray tracing simulations have been performed at different frequencies and the capacity has been estimated with the same antenna pattern. The results are shown in Fig. 8 for the radio link T2-R2. In a first time, the effect of the frequency has been studied for a single MIMO array ( $3 \times 3$  – spacing=3 cm). If the path loss effect is not taken account, the capacities slightly increase with the frequency. This is explained by the enhancement of the decorrelation of the array sensors. But, if the path loss frequency effect is considered, the capacity strongly decreases (25 bps/Hz) while the frequency increases.

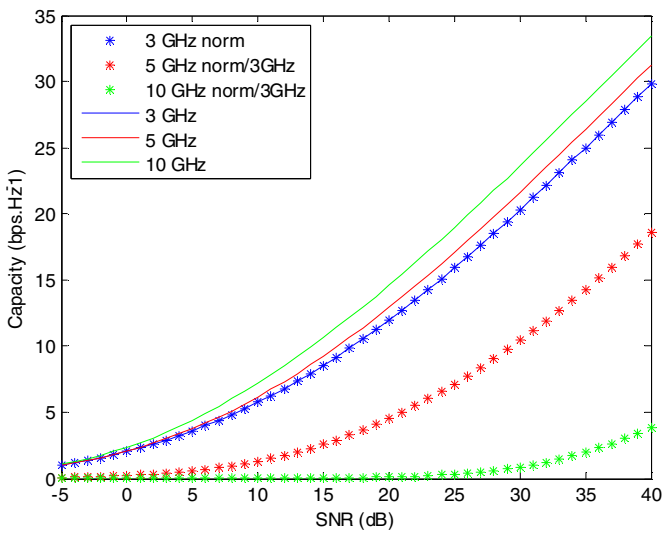


Fig. 8 Mean capacity versus SNR of a  $3 \times 3$  array according with a 3cm antenna spacing and the same antenna pattern

Some others capacities simulations have been performed with a sensor spacing set to  $\lambda/2$  and  $\lambda$  (Fig. 9). These results can be compared to the study of Garcia & Al [5]. They kept a constant spacing of one wavelength between sensors and show a capacity decrease while the frequencies increase. Our results are in agreement with them, but the increase of capacity is very low (2-4 bps/Hz) especially for a sensor spacing of  $\lambda$ .

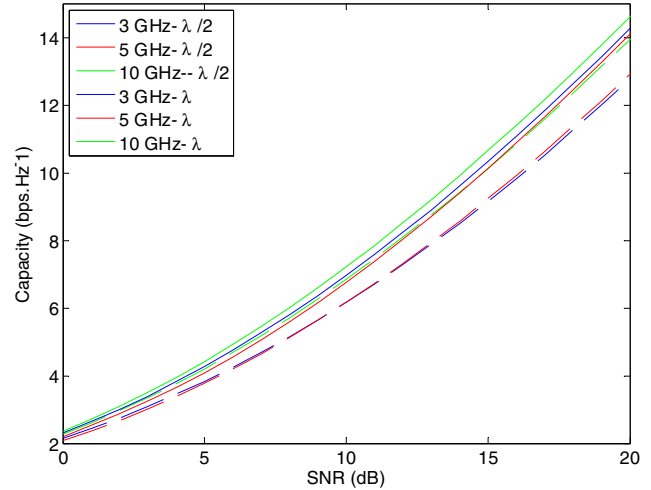


Fig. 9 Mean capacity versus SNR of a  $3 \times 3$  array according to simulation frequency and sensor spacing for one antenna pattern (5 GHz)

### D. Capacity Simulation for Different Locations

Ray tracing simulations have been achieved for each measured location. The capacity has been studied with the path loss effect in order to exactly evaluate the difference of the capacity in a residential flat. The Fig. 10 presents a maximum variation of 20 bps/Hz over the flat. All the MIMO matrix have been normalized to the matrix of the first measurement location.

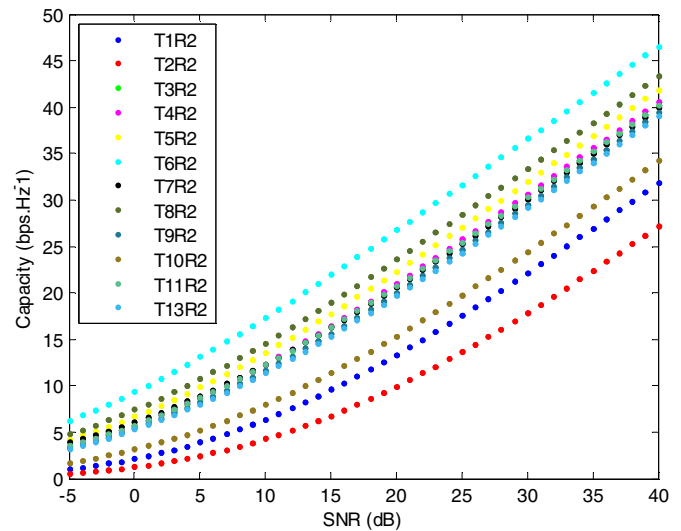


Fig. 10 Simulated capacity versus SNR of a  $3 \times 3$  array (spacing= 3cm) 5 GHz.

### E. Measured and Simulated MIMO Capacities Comparison

The simulations have been compared to the measurement especially for the transmitter location 2 and 6 which correspond to the better and the worst capacity results in the flat. In the both case, the simulation is slightly undervalued (Fig. 11 & 12). That could be explained by a loss of rays or a lack of diffusion modelling in the simulation. The link T2R2 is more affected by this simulation default because at this location, the channel is composed of multipaths stronger than the direct path. For the location T6, the direct path is higher than the multipaths and so the channel could be less affected by the phenomena of diffusion, or omitted rays.

## VI. CONCLUSION

An analysis of the modelling parameters of the propagation channel has been realized in order to evaluate its impact on the MIMO capacity. The antenna pattern effect has been evaluated and the frequency dependence of the capacity has been analysed. The simulation results show that the frequency impact on the capacity is mainly due to the path loss in a typical residential flat. The comparison of measurement and simulation reveals an undervaluation of the simulation and shows that the ray-tracing tool needs to be improved. Indeed, a diffusion modelling could give more accuracy and improve the space-time characterisation of the propagation channel.

## REFERENCES

- [1] G. J. Foschini and M. J. Gans, "On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas," *Wirel. Pers. Commun.*, vol. 6, pp. 311-335, 1998.
- [2] M. Landmann, W. Kotterman, and R. S. Thomä, "On the Influence of Data Models on Estimated Angular Distributions in Channel Characterisation," presented at Eucap, Edinburgh, 2007.
- [3] G. Tesserault, N. Malhouroux, and P. Pajusco, "Multi-frequencies characterization of building materials: Angular and polarization analysis", *EuCAP 2007*.
- [4] P. Pajusco, G. Tesserault, N. Malhouroux, and C. Sabatier, "Novel array structure for space-time characterization of the UWB channel", *PIMRC 2008. IEEE 19th International Symposium on*, 2008..
- [5] A. Intarapanish, C. Thongsoa, C. Sactivaw, *IEEE 2007 International symposium on microwave, antenna, propagation and EMC Technologies for wireless Communications*, pp.160163

- [6] A. P. Garcia, L. Rubio, and J. A. Diaz, "Experimental analysis of the frequency impact on the MIMO channel capacity between 2 and 12 GHz in an office environment," *Antennas and Propagation International Symposium, 2007 IEEE*, 2007

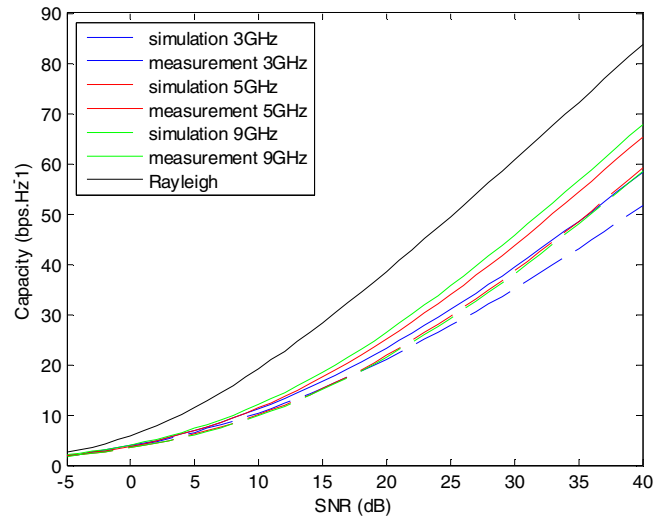


Fig. 11: Mean capacity versus SNR of a  $7 \times 7$  array at 3,5,9 GHz for the link T6-R2

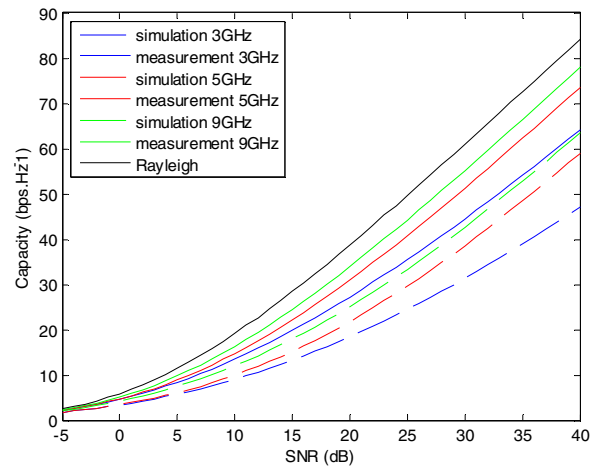


Fig. 12: Mean capacity versus SNR of a  $7 \times 7$  array at 3,5,9 GHz for the link T2-R2