A Statistical 3D MIMO Radio Channel Model for UMTS

Abstract — **This paper presents a 3D single bounce MIMO radio channel model and compares it with a 2D one. The main motivation is that existing models, which account only for a 2D environment, are not able to properly simulate a radio channel, in particular for indoor scenarios (which consists of many obstacles). Results show that angular spread increases considering the 3D model, for all the considered scenarios. The relative MIMO capacity gain for the 3D model is approximately 20 % higher than in the 2D one, for a 16×16 MIMO system, in a street and medium-sized room scenarios.**

I. INTRODUCTION

Channel models are used to get a prediction of the radio environment in scenarios, without the need of doing a complex and time consuming measurement campaigns. These models can roughly be divided into two groups: deterministic and stochastic ones. The former is used if a specific environment needs to be modelled, while the latter gives realistic results, without exactly modelling an environment. Geometrically Based Single Bounce Channel Models (GBSBCMs), such as the COST 259 one [1], are stochastic ones, and have been used for many years, because of their low complexity and good accuracy. In such models, the signal is transmitted from the transmitter (Tx) to the receiver (Rx) via scatterers, which results in multipath signals at the Rx.

Multiple-Input Multiple-Output (MIMO) systems have appeared in order to enhance radio systems, like the Universal Mobile Telecommunications System (UMTS), since they increase user capacity, range and throughput in a variety of environments (most notably those that have a low interference such as small and/or isolated cells). The MIMO approach is to use spatial diversity by applying multiple antennas on both ends of the radio link and to establish parallel links in between them. If the links are independent, a gain in the radio channel can be observed, leading to that are a few times greater than the ones for Single-Input Single-Output (SISO) systems. The independence of the links between input and output is related to propagation conditions in the radio channel (i.e., the correlation between Channel Impulse Responses (CIRs)), thus, the gain of MIMO systems is possible only in multipath environments, and depends on how strong the multipath phenomenon is. A high correlation leads to a low MIMO capacity, and vice versa. The MIMO system gain is related to some parameters, as numbers of input and output antennas and spacing between them, and the time resolution of the Rx.

The channel model presented in this paper simulates the CIRs for each antenna-pair separately, which allows one to calculate the correlation between them, hence, to obtain the MIMO capacity.

Many channel models for MIMO systems have appeared in the literature. However, with the exception of a few recent results, they are largely focused on two dimensional (2D) propagation, i.e., propagation on the horizontal plane, and the impact of elevation angle is not considered. The assumption of 2D propagation breaks down in some propagation environments, like indoor ones, which consist of many obstacles that are really not deployed on this plane. In fact, there is a real scarcity of published models for the elevation spectrum, channel models and parameters for propagation that include a three dimensional (3D) component [2]. These are the aspects that are considered in this paper: introduction of a 3D single bounce MIMO radio channel model for UMTS.

The Radio Channel Parameters (RCPs) of the channel model and the gain of a MIMO system should be checked in different conditions of propagation, and with dissimilar distributions of the scatterers. In this paper, different scenarios are analysed, focusing on indoor ones, with four cases being considered, for receiver time resolutions of 0.1 and 260 ns: small-, medium-, and large-size rooms, as well a street one.

Section II presents the developed model and its theoretical aspects. The considered scenarios, as well as the results for SISO and MIMO channel are evaluated and looked in detail in Section III. In Section IV, the main conclusions are drawn.

II. DEVELOPED MODEL

A. 2D GBSB channel model

The 3D developed model is based on the 2D GBSBCM created at IST/TUL [3]. The main idea behind this model is that the multipath characteristic of a radio channel is the result of signal bounce over numerous scatterers. Additionally, every scatterer is a source of a multipath component (MPC). Each scatterer is described by random, complex reflection coefficient ($|\Gamma_s|$, Φ_s), which determines the influence on the MPC. It is worth to notice that scatterers reflection coefficients are generated randomly. After bouncing off the scatterer, the MPC changes its magnitude and phase.

In conclusion, the GBSB channel model can be considered as a combination of deterministic (parameters like Angle of Arrival (AoA), Angle of Departure (AoD), and Time of Arrival (ToA), which are computed based on environment geometry) and statistical features (coordinates of scatterers are generated randomly and each scatterer is described by a random reflection complex coefficient).

B. 3D Approach

A 3D point is considered to be defined by its spherical coordinates (r, θ, φ), so each receiver, transmitter and scatterer position in the 3D domain, is converted in terms of spherical coordinates. The elevation and azimuth AoA/ AoD can be obtained according to simple geometrical considerations. From elevation and azimuth angles, angle spreads are obtained, and the RMS directional spreads achieved. For the AoA, RMS angle spread is calculated according to

$$\sigma_{\Omega_{AoA}} = \sqrt{\sigma_{\theta_{AoA}}{}^2 + \sigma_{\varphi_{AoA}}{}^2} \quad (1)$$

where:

- σ_θ - RMS elevation spread,
- σ_φ - RMS azimuth spread.

As a result of the physical location of the scatterers being represented in 3D, an MPC can arrive from any azimuth co-elevation pair of angles defined by the scatterer position within the propagation path. Each MPC is characterised by seven different parameters: by its delay τ, amplitude, phase, azimuth and elevation AoD, φ_{AoD} and θ_{AoD}, and azimuth and elevation AoA, φ_{AoA} and θ_{AoA}. The delay of an MPC corresponds straightforward to path length, and is measured in reference to the delay of the Line of Sight (LoS) component. The MPC normalised amplitude, A_R, and the MPC phase, Φ_R, are obtained according to

$$A_R = \frac{|\Gamma_s|}{\sqrt{4\pi} \cdot (d_{ts} + d_{sr})} \quad (2)$$

where:

- d_{ts} - distance between Tx and Scatterer
- d_{sr} - distance between Rx and Scatterer

$$\Phi_R = \left(\frac{(d_{ts} + d_{sr})}{\lambda} - \left\lfloor \frac{(d_{ts} + d_{sr})}{\lambda} \right\rfloor \right) \cdot 2\pi + \Phi_s \quad (3)$$

C. 3D antenna radiation pattern

The problem of obtaining the 3D antenna radiation pattern also needs the attention on the development of the 3D GBSB channel model. In almost all cases, antenna manufacturers do not make available full three-dimensional radiation patterns, but only the patterns in the horizontal and vertical planes (or, perhaps only the half-power beamwidth (HPBW) for the vertical plane). So, two main approaches are considered and taken into account:

- "Real" 2D antenna patterns,
- Theoretical 3D antenna patterns.

In the first case, 2D antenna patterns files (available from the manufacturers) are used, which contain the gains (for a given angle) of the horizontal and vertical plane, and then a 3D interpolation base on [4] is done, with a small relative error. This approach allows the use of any antenna radiation pattern.

In the second case, a theoretical radiation pattern of half wavelength dipole is considered, as well as arrays of these dipoles. In both cases, the vertical plane of the radiation pattern is symmetric, having a unique lobe. Moreover, for the case of dipoles, the gain depends only on the elevation angle; as for the arrays, it not only depends on the elevation angle, but also on the number of dipoles, the distance between them and the phase shift.

III. RESULTS ANALISIS

A. Scenarios

In order to make a realistic investigation into the differences introduced by 3D, it is necessary to choose appropriate scenarios for the simulations. In particular, indoor scenarios are the object of this investigation. The 3D GBSBCM is designed for cellular mobile communications, such as UMTS.

The following scenarios were taken for simulations:

- Small-size (length ~ 6 m) office room (pico-cell),
- Small-size (length ~ 6 m) normal room (pico-cell),
- Medium-size (length ~ 12 m) room (pico-cell),
- Large-size (length ~ 100 m) room (micro-cell),
- City street scenario (micro-cell).

Scenarios have been defined for the single bounce case. The cluster density and number of scatterers were taken from [5]. Table 1 summarises the characteristics of each considered scenario [6].

Table 1
Input parameters for the considered scenarios

Case	small office room	small normal room	large room	street
Scenario type	pico-cell		micro-cell	
Environment				
Propagation conditions	LoS			
Shape of environment	sphere		spheroid	ellipsoid
Cluster density [m^{-3}]	0.02		0.00015	0.00005
Number of clusters	5		15	10
Number of scatterers	2		10	10
Tx/Rx distance [m]	2.5		45	100
System				
Frequency [GHz]	2			
Bandwidth [MHz]	5			
Wavelength [m]	0.15			
Tx power [W]	1			

The small-size office room is the specific case of a room with a metallic roof. The shape of the scattering region for this scenario is the sphere, the height being set to 3 m. The scenario of the small-size normal room is very similar to the previous one, with the exception of the roof: the roof is, e.g., concrete, or plaster, but not metallic.

The large-size room is the specific case of an airport or a shopping centre. Even though this situation can be treated as a pico- or a micro-cell, for the purpose of this paper only the micro-cell is considered. The radius of the scattering region (spheroid) is set to 50 m, and the BS is located in its centre (placed on the main hall). In this specific type of environment, one analysed the RCPs variation with the Rx sensitivity. As a direct consequence of increasing Rx sensitivity, less rays will be detected by the Rx.

The street scenario is a scenario typical for an urban environment. The street has a grid pattern and is bounded by buildings, which are the reason for wave guiding along the street canyon.

B. SISO Channel

The aim of this research is to check how 3D influences RCP (i.e., spatio-temporal and power parameters), depending on the considered scenario. All presented values are the average of 200 simulations in order to have reliable statistics for the RCPs.

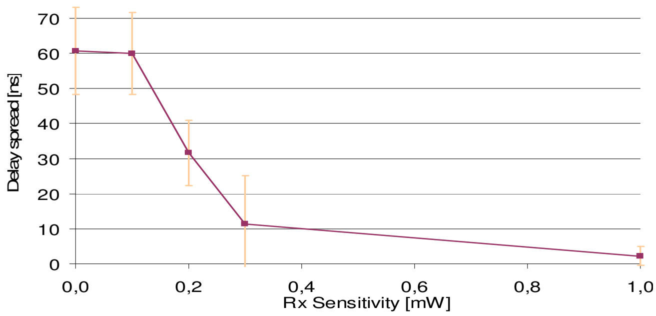
In the case of the small normal room, Table 2, the major difference between 2D and 3D RCPs is the angle spread, as expected. This can be explained by the simple fact of considering the 3D domain by itself: one extra dimension has the effect of increasing the angle spread, since the shape of the scattering region goes from a circle in the 2D case to a sphere in the 3D one. A slightly increase in the delay spread for the 3D case is also observed, also related with the previous situation.

Table 2
RCPs for 2D and 3D and for different small rooms.

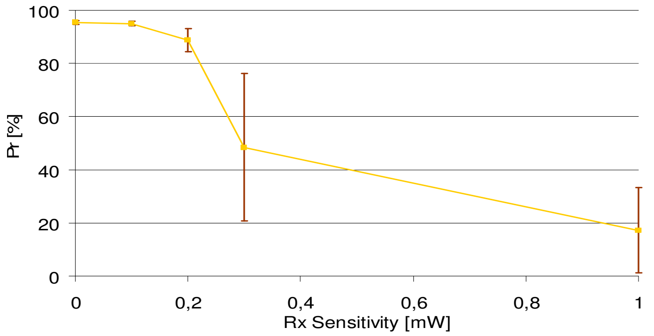
	small normal room				small office room	
	2D		3D		3D	
	mean	std	mean	std	mean	std
τ_{max} [ns]	16.0	2.5	17.7	3.1	18.1	3.3
σ_τ [ns]	3.8	0.9	4.5	0.9	4.6	1.0
σ_Ω [°]	38.9	14.1	60.9	10.7	63.9	10.1
ω_{AoA} [rad/μs]	192.8	101.2	251.4	85.9	252.5	79.2
Pr [%]	49.3	11.0	48.5	9.5	55.0	8.5
γ	1.0	0.3	1.2	0.2	1.1	0.2

The major difference between the normal and office small room is the fact that the latter has an extra MPC due to the reflection on the roof. This means higher received power due to an additional single bounce compared to the LoS. This fact is shown on the difference of *Pr* (percentage of power with a single bounce) between the two difference scenarios. Having one more reflecting object, increases also the angle spread as well the delay spread, even though the small differences. The average power decay, γ, indicates indirectly the value of the overall attenuation of the radio link. The lower the value of the average power decay, the more rich in reflectors the environment is. This conclusion is well proved by the lower value in the small office room compared to the normal one.

Figure 1 presents the two most interesting RCPs to analyse when the Rx sensitivity is changed.



(a) Delay spread.



(b) Relative single bounce received power.

Figure 1. Delay spread and relative single bounce received power for the large room scenario as a function of the Rx sensitivity.

When the Rx sensitivity takes higher values, delay spread decreases. The Rx sensitivity influences the number of MPCs that are detected, hence, when lower values of Rx sensitivity are assumed, all MPCs are detected, even the ones with lower power. However, when higher values are considered, just the MPCs with high power (which correspond mainly to the interfering objects that are near the Rx) are detected by the Rx; obviously, this causes a dramatically decreases on the delay spread.

The received power due single bounce relative to LoS proves that less MPCs are detected when lower values of Rx sensitivity are considered. This difference is very relevant, 78 %, between the two limit values for the considered interval. In the limit, just the MPC due to LoS is detected, and is the one considered to the received signal.

C. MIMO Channel

The main feature of a MIMO system, which distinguishes itself from other systems, is the fact of having multiple antennas on Rx and Tx. As expected, an increase of the number of antennas leads always to a growth of capacity gain, since more antennas allow one to establish more subchannels in the MIMO system. This results in achieving a higher gain for the system. Moreover, the capacity gain grows more in the case of higher time resolution for all scenarios.

Figure 2 shows the comparison among scenarios, in what concerns MIMO capacity gain (for 260 ns of time resolution).

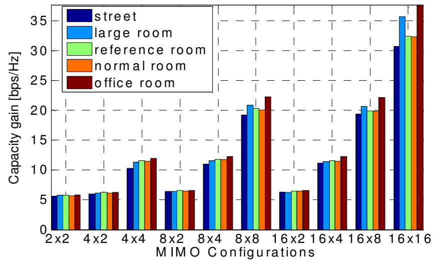


Figure 2. MIMO gain for the different scenarios, for a time resolution of 260 ns.

The greatest advantage of a MIMO system is observed for the small room scenario, in particular for the office one, which is the scenario with the highest capacity gain in all cases, because a 3D environment is much more important in this type of scenarios. It is also relevant to point out the difference on the MIMO capacity gain between small-size office and normal rooms. Despite the former having only one more MPC than the latter (which is irrelevant in a SISO channel or even in a 2×2 MIMO), for a 16×16 MIMO the difference in terms of MIMO capacity gain cannot be neglected. Moreover, the office room scenario presents a MIMO capacity gain 12 % higher than the normal one. It can also be concluded that asymmetric antennas configurations present small capacity gain differences compared with symmetric ones, e.g., the 8×8 MIMO presents almost the same capacity gain as the 16×8 one. The reference room is the scenario with the worst results, due to the highest correlation between links (all results can be seen in [6]).

Figure 3 presents, for 0.1 ns time resolution, the difference in the relative MIMO gain, between the 3D and 2D model.

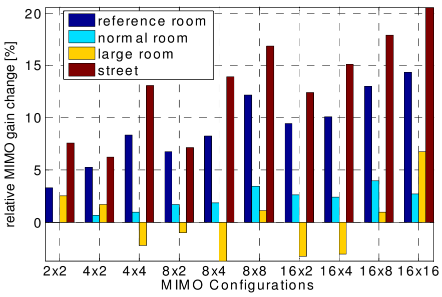


Figure 3. Difference in relative MIMO gain between 3D and 2D, for a time resolution of 0.1 ns.

The street scenario is the one in which the best results in comparison with the 2D model is obtained, for different antennas configurations, achieving over than 20 % for the 16×16 MIMO case. For the same size of the MIMO system, the reference room is characterised by a relative MIMO gain equal to 10.6, which is 14.4 % higher in the case of the 3D model compared to the 2D one. The small normal and the large room scenarios are the ones with the smallest differences between the two models, the latter being even worst than the 2D model for some MIMO systems. For the 8×4 MIMO, the relative MIMO gain of the 3D model is 3.7 % lower than the 2D one.

IV. Conclusions

This paper addresses the differences between 2D and 3D channel models, and their impact on MIMO systems. Different scenarios are analysed, focusing on indoor ones, with four cases being considered, for receiver time resolutions of 0.1 and 260 ns: small-, medium-, and large-size rooms, as well a street one.

As expected, the differences between the RCPs of office and normal room are very small, however, the fact that the office room has an extra MPC due the reflection on the roof is well shown with more 7 % of received power due single bounce. It is also shown that AoA spread increases for the 3D model in the normal room scenario, this difference being the main one between 2D and 3D models.

The relative capacity gain of a MIMO system is mainly regulated by the dimension of the antenna set. The number of MIMO antennas and spacing between them are the main factors. System time resolution influences also MIMO capacity gain. In fact, the capacity gain grows more in the case of higher time resolution for all scenarios. One observes also that asymmetric antennas configurations present small capacity gain differences compared to symmetric ones.

The greatest advantage of a MIMO system is observed for small room scenarios, in particular for the small office room, which is the scenario with the highest capacity gain in all MIMO systems. This happens because a 3D environment is much more important in small dimensions scenarios.

Finally, the relative MIMO capacity gain for the 3D model is approximately 20 % higher than in the 2D one, for a 16×16 MIMO configuration, in the street scenario, for 0.1 ns of time resolution.

References

[1] Correia,L.M. (ed.), *Wireless Flexible Personalised Communications, COST 259 Final Report*, John Wiley & Sons, New York, NY, USA, 2001.

[2] Shafi,M., Zhang,M., Smith,P.J., Moustakas,A.L. and Molisch,A.F., "The Impact of Elevation Angle on MIMO Capacity", in *Proc. of ICC'2006 – IEEE International Conference on Communications*, Istanbul, Turkey, June 2006.

[3] Marques,M.G. and Correia,L.M., "A Wideband Directional Channel Model for Mobile Communication Systems", in Chandran, S. (ed.), *Adaptive Antenna Arrays*, Springer, Berlin, Germany, 2004.

[4] Gil,F., Claro,A.R., Ferreira,J.M., Pardelinha,C. and Correia,L.M., "A 3D Interpolation Method for Base-Station-Antenna Radiation Patterns", *IEEE Antennas and Propagation Magazine*, Vol. 43, No. 2, April 2001.

[5] Czink,N., *The Random-Cluster Model – A Stochastic MIMO Channel Model for Broadband Wireless Communication Systems of the 3rd Generation and Beyond*, Ph.D. Thesis, Technical University of Vienna, Vienna, Austria, Dec. 2007.

[6] Leonardo,F., *A Statistical 3D MIMO Radio Channel Model for UMTS*, M.Sc. Thesis, IST, Lisbon, Portugal, 2008.