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Research Article

Map-Based Channel Model for Urban Macrocell Propagation Scenarios

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The evolution of LTE towards 5G has started and different research projects and institutions are in the process of verifying new technology components through simulations. Coordination between groups is strongly recommended and, in this sense, a common definition of test cases and simulation models is needed. The scope of this paper is to present a realistic channel model for urban macrocell scenarios. This model is map-based and takes into account the layout of buildings situated in the area under study. A detailed description of the model is given together with a comparison with other widely used channel models. The benchmark includes a measurement campaign in which the proposed model is shown to be much closer to the actual behavior of a cellular system. Particular attention is given to the outdoor component of the model, since it is here where the proposed approach is showing main difference with other previous models.

1. Introduction

The research community is currently developing the fifth generation of mobile communication systems (5G). From early 2012, ITU-R set up a research programme to address "IMT for 2020 and beyond." In this framework, detailed investigations of the key elements of 5G are on track from several stakeholders in the 5G community. Of special relevance is the contribution from the European Union METIS project [1]. Several technology components have been proposed, all of them being verified through extensive simulations. In this regard, it is important to highlight the need to use realistic (no synthetic) scenarios. Past experience with other study works performed in 3GPP has shown the need for a proper characterization of realistic effects. Some conclusions reached with synthetic simulations have turned out to be incorrect once the proposed techniques were applied to the field. In this sense, METIS definition of the 5G concept is driven by a set of twelve realistic test cases [2] and the same approach towards realistic channel models can be seen in the 3GPP simulation activities.

In the evaluation of the 5G technology component candidates, channel models are of paramount importance to guarantee an accurate modeling of the propagation conditions. The ITU-R defined in [3] a channel model that can be parameterized to cover a different set of test environments, ranging from indoor to rural cases. The main features of this model are quite similar to the Extended Spatial Channel Model (SCME) defined by the WINNER project [4] and also described by the 3GPP [5]. Given the complexity of the small scale model, ITU-R also specified in [3] an alternative method based on the usage of a correlation matrix, derived as the Kronecker product of the polarization covariance matrix and the correlation matrices calculated at the base stations and at the user equipment, which is also suggested by 3GPP for the conformance specification of user equipment [6].

All these widely used models lack the incorporation of a 3D characterization of the scenario layout, which is a must for the future evaluation of cellular systems [7]. New map-based models considering the location of streets and buildings must be developed in order to take the elevation dimension and the resulting changes in radio propagation into account.

Recently, 3GPP issued a 3D channel model that mainly focuses on the extensions of the small scale modeling [8]. Concerning path loss characterization, the proposed model is very similar but includes calculation of distances in 3D and also an extension for the outdoor-to-indoor propagation modeling. This 3D model is nowadays being used in the evolution of LTE, most specially in the analysis of dense deployments.

Another alternative to make an adequate characterization of propagation effects is the use of ray tracing [9]. Ray tracing approximates the propagation launching a set of discrete rays to different directions and their propagation is traced by computing the interactions of rays (like reflection, diffraction, or dispersion), with the surrounding objects alongside the propagation in the environment. Although ray tracing is very accurate it needs a complete knowledge of the environment and its computational burden is unmanageable for large deployment scenarios.

In large and complex deployment scenarios, new alternatives for 3D modeling should be studied keeping in mind the tradeoff between realism and implementation complexity. This paper proposes a propagation modeling alternative for urban macrocell scenarios that, being much simpler than ray tracing, still allows for a proper characterization of real environments. As compared with ray tracing, the proposed model is equivalent to a single-ray approach, provided that the total loss is computed as a summation of three terms representing free space loss, the diffraction loss from rooftop to the street, and the reduction due to multiple screen diffraction past rows of buildings. Section 2 presents the model, including small and large scale effects. Section 3 compares this model with 3GPP and ITU-R widely used alternatives and, finally, Section 4 concludes the paper.

2. The Proposed Model

This scenario refers to the situation in which the base station is situated over a building rooftop and has dominant visibility of users. For the urban macrocell scenario, most part of the signal reaches users via diffraction and main propagation path is over buildings [10]. This propagation scenario is similar to the scenario assumed by ETSI in [11] and the same approaches apply. This model is divided into two parts, the small scale and the large scale characterization.

Channel models usually use two different sets of channel parameters. The first one is related to the large scale parameters, such as shadow fading and path loss. The second one concerns small scale parameters, including Angle of Arrival (AoA) and Angle of Departure (AoD) or delay of the rays.

In order to generate channel samples between one transmitter and one receiver, mobility and exact location of both ends must be known. Based on this information all large scale parameters are generated, followed by the small scale parameters.

2.1. Small Scale Parameters. Concerning small scale parameters characterization, we propose the use of ITU-R M.2135 UMa model [3], although three issues must be clarified. Firstly, it is worth noting that ITU-R M.2135 UMa is a 2D model not a 3D model as could be desirable. However, it has proven valid for conventional MIMO structures. Secondly, regarding the validity of such model for dynamic simulations in which the position of users changes over time, we propose,

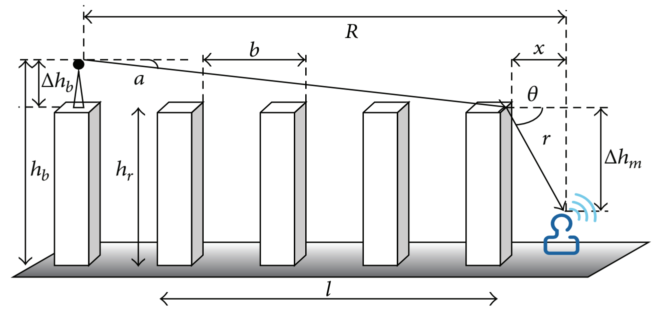

Figure 1: Geometry of the large scale model.

assuming that the conditions for rays and cluster generation remain static along a certain correlation length, 50 meters for the urban macrocell propagation scenario. After this distance, new cluster and rays must be generated according to the new geometry. Finally, in [3] these models are particularized for LoS or NLoS conditions. For synthetic simulations these conditions are randomly selected. However, for realistic test cases sight condition will be reevaluated for each correlation length based on the actual position of transmitter and receiver.

2.2. Large Scale Modeling. The total transmission loss in decibels is expressed as the sum of free space loss, the diffraction loss from rooftop to the street, and the reduction due to multiple screen diffraction past rows of buildings; that is,

$$L(R) = \begin{cases} L_{fs} + L_{rts} + L_{msd} & \text{if } L_{rts} + L_{msd} > 0 \\ L_{fs} & \text{if } L_{rts} + L_{msd} \leq 0. \end{cases} \quad (1)$$

Figure 1 illustrates the used geometry and the set of variables that modify the model response.

Given a mobile-to-base separation R, the free space loss between them is given by

$$L_{fs} = -10 \cdot \log_{10}\left(\frac{\lambda}{4\pi R}\right)^2. \quad (2)$$

The diffraction from the rooftop down to the street level gives the excess loss to the mobile station [12]:

$$L_{rts} = -20 \cdot \log_{10}\left[\frac{1}{2} - \frac{1}{\pi}\arctan\left(\operatorname{sign}(\theta)\sqrt{\frac{\pi^3}{4\lambda}r(1-\cos\theta)}\right)\right], \quad (3)$$

where, according to Figure 1,

$$\theta = \tan^{-1}\left(\frac{|\Delta h_m|}{x}\right)$$
$$r = \sqrt{(\Delta h_m)^2 + x^2}, \quad (4)$$

being Δh_m the difference between the last building height and the mobile antenna height and x the horizontal distance between the mobile and the diffracting edges.

The multiple screen diffraction loss from the base antennas due to propagation past rows of buildings depends on the base antennas height relative to the building heights and on the incidence angle [13]. A criterion for grazing incidence is the settled field distance, d_s:

$$d_s = \frac{\lambda R^2}{\Delta h_b^2}, \tag{5}$$

where Δh_b is the base station antenna height, h_b, relative to average rooftop h_r. Then for the calculation of L_{msd}, d_s is compared to the length of the path covered by buildings l.

If $l > d_s$,

$$L_{mds} = L_{bsh} + k_a + k_d \log_{10}\left(\frac{R}{1000}\right) + k_f \log_{10}(f) - 9\log_{10}(b), \tag{6}$$

where

$$L_{bsh} = \begin{cases} -18\log_{10}(1+\Delta h_b) & \text{for } h_b > h_r \\ 0 & \text{for } h_b \le h_r \end{cases} \tag{7}$$

is a loss term that depends on the base station height:

$$k_a = \begin{cases} 54 & \text{for } h_b > h_r \\ 54 - 0.8\Delta h_b & \text{for } h_b \le h_r,\ R \ge 500 \\ 54 - 1.6\Delta h_b \dfrac{R}{1000} & \text{for } h_b \le h_r,\ R < 500, \end{cases}$$

$$k_d = \begin{cases} 18 & \text{for } h_b > h_r \\ 18 - 15\dfrac{\Delta h_b}{h_r} & \text{for } h_b \le h_r, \end{cases} \tag{8}$$

and $k_f = 0.7(f/925-1)$ for medium sized cities and suburban centers with medium tree density whereas $k_f = 15(f/925-1)$ is for metropolitan centers. Note that frequency is expressed in MHz in these equations.

On the other hand if $l \le d_s$, a further distinction has to be made according to the relative heights of the base station and the rooftops:

$$L_{msd} = -10 \cdot \log_{10}\left(Q_M{}^2\right), \tag{9}$$

where

$$Q_M = \begin{cases} 2.35\left(\dfrac{\Delta h_b}{R}\sqrt{\dfrac{b}{\lambda}}\right)^{0.9} & \text{for } h_b > h_r \\ \dfrac{b}{R} & \text{for } h_b \approx h_r \\ \dfrac{b}{2\pi R}\sqrt{\dfrac{\lambda}{\rho}}\left(\dfrac{1}{\vartheta} - \dfrac{1}{2\pi+\vartheta}\right) & \text{for } h_b < h_r, \end{cases}$$

$$\vartheta = \tan^{-1}\left(\frac{\Delta h_b}{b}\right),$$

$$\rho = \sqrt{\Delta h_b{}^2 + b^2}. \tag{10}$$

Figure 2: Map of the site in Valencia, including the location and azimuth of the cell under study.

In this model, minimum coupling loss is set to 70 dB.

Concerning outdoor-to-indoor characterization, we propose the same approach as in the WINNER+ project [14]. Note also that a complete Matlab implementation of the model can be found at the METIS webpage [15].

3. Comparison with Other Models

The comparison between the three alternatives considered in this paper, that is, the IMT-A model, the 3GPP model with 3D extension, and the proposed model, referred to as map-based model, was made using real measurement. These measurements were carried out in the urban area of Valencia, Spain. The transmit antenna was a real UMTS base station located in the city operating at 2100 MHz. The base station was located above rooftop at 37 m. The equipment used for the measurements was a drive-test terminal equipped with the software Nemo-Outdoor. Receive Signal Code Power (RSCP) measurements were taken on a uniform grid of outdoor static positions. Measured points were spaced 10 meters, half the typical correlation distance in an urban scenario, storing 60 samples during 30 consecutive seconds (data was captured every 0.5 seconds). This measurement time was 1000 times the coherence time of a Rayleigh-Fading Channel corresponding to a low mobility or pedestrian user moving at 3 km/h, so that the average of the samples could be considered independent of the fast fading.

With these resulting levels of RSCP, we obtained the approximate values of the path loss at each point taking into account the transmit power of the base station, the gain of the mobile terminal, and the gain of the base station antenna for each point by calculating the approximate values for azimuth and elevation and the exact antenna pattern.

Figure 2 shows the area where measurements were taken. It includes an irregular pattern of buildings with different heights, sidewalks, parking lots, and also a garden area. We chose this location because of its heterogeneity, far away from the classical regular Manhattan grid assumed in other scenarios.

Once the area under study has been identified, a proper clutter height must be created. This is simply a matrix in which each cell identifies the exact height of the corresponding coordinate with respect to the ground. Figure 3 shows an example of such a clutter height with 10 m resolution.

The clutter height is used in the model proposed in this paper to create the propagation profile between transmitter

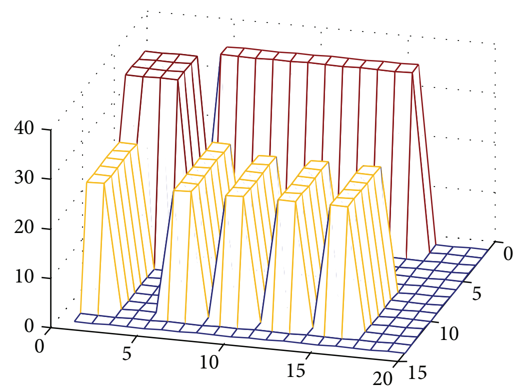

Figure 3: Map model used for the channel prediction.

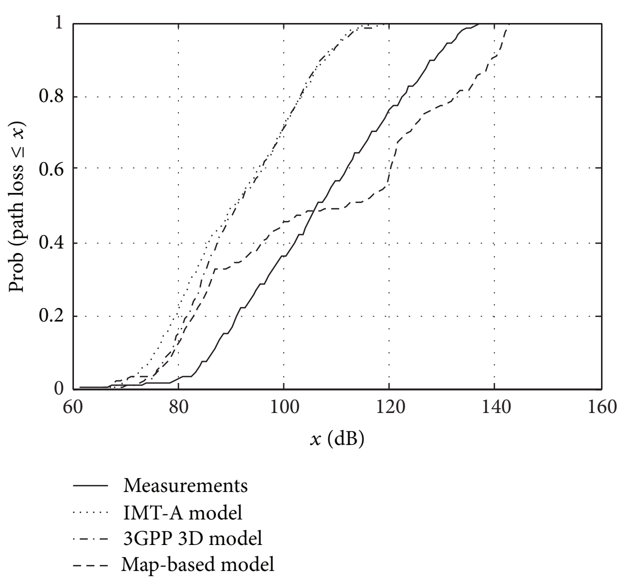

Figure 4: CDF of the path loss values in the area under study.

and receiver and calculate the exact values of the variables represented in Figure 1. However, in order to improve the level of realism of the other two models compared in this section, this map was also used in the IMT-A and 3GPP models. Unlike their current stochastic approach for determining LoS/NLoS conditions, we propose to derive the LoS or NLoS conditions directly from the visibility of transmitter and receivers using this 3D modeling of the area under study.

Figure 4 shows the Cumulative Distribution Function (CDF) of the path loss predictions provided by the three models compared in this paper and the actual path loss in the area. We can see the high similarity between the IMT-A and the 3GPP 3D models. They slightly differ in the lowest values of path loss, that is, with LoS, but are similar for high path losses.

Concerning the map-based model, it is worth mentioning that this is very similar to the 3GPP 3D and IMT-A model in case of LoS, that is, for the lowest range of path loss values, but differs considerably for higher values. In fact, in the median the map-based model predicts a path loss 20.5 dB

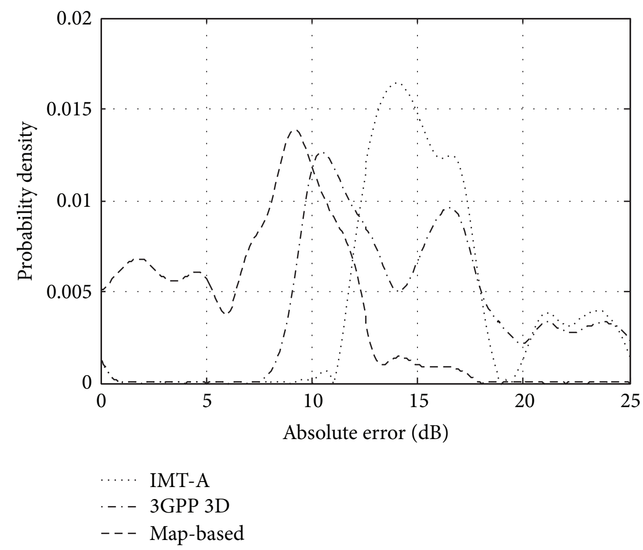

Figure 5: Probability distribution of the absolute error in the path loss estimation.

greater than the IMT-A and 3GPP 3D models. However, when comparing with the real measurements, the distance in the median of the map-based model and the real measurements is only 4.7 dB, being this difference 15.84 dB when comparing the other two models with the actual data. With LoS, all of them are optimistic with respect to the actual behavior of the propagation probably due to the presence of trees.

Figure 5 shows the probability distribution of the absolute error of the predictions for the three models under study. Again, the map-based model features lower error as compared with the other two models. In fact, the error of the map-based model as compared with the real measurements is always lower than 18 dB, being the average of only 7.21 dB. The IMT-A model is the one showing a higher prediction error, being the average absolute error of 15.85 dB. Moreover, the minimum error is around 10 dB. Finally, the 3GPP 3D model is between the other two, although the average absolute error is also very high, of 14.75 dB.

4. Conclusion

In this paper, an outdoor model for urban macrocell propagation scenarios has been described. This model is map-based and uses clutter height data to perform path loss predictions. A comparison of this model and the IMT-A and 3GPP models based on real measurements shows that significant improvements can be achieved when considering the layout of buildings while keeping the simplicity in the calculations. Moreover, measurements show that the proposed model presents an average absolute error of 7.21 dB, whereas 3GPP and IMT-A models show an error of 14.75 and 15.85 dB, respectively.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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