



# Fast algorithm for radio propagation modeling in realistic 3-D urban environment

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**Abstract.** Next generation wireless communication systems will consist of a large number of mobile or static terminals and should be able to fulfill multiple requirements depending on the current situation. Low latency and high packet success transmission rates should be mentioned in this context and can be summarized as ultra-reliable communications (URC). Especially for domains like mobile gaming, mobile video services but also for security relevant scenarios like traffic safety, traffic control systems and emergency management URC will be more and more required to guarantee a working communication between the terminals all the time.

between transmitter and receiver. Both Rayleigh and Rician fading will be precomputed for the correspondent situations and just added to the path loss to achieve shorter computation times. Further, it is demonstrated that the employed algorithm is able to outperform the state-of-the-art approach described in Sect. 2.

The remainder of this paper is organized as follows: in Sect. 2 we give a short overview about the scenario layout and the user mobility. In Sect. 3 we present the path loss models and discuss the commonly used parameters. The computation of fast fading is presented in Sect. 4 while the simulation results are shown in Sect. 5.

## 1 Introduction

In order to evaluate the performance of next generation mobile communication systems in realistic deployment scenarios, system level simulation tools must be capable of integrating various models that reflect network deployment (e.g., antenna locations, elevation, orientation, transmit powers), user mobility and communication behavior, as well as service characteristics. The need for modeling system aspects and use cases of next generation mobile networks in a more realistic manner system is already acknowledged by European 5G research project ICT-317669 METIS (2013). In this paper we present a fast method for computing the path loss of micro and macro cells in a realistic, three dimensional urban environment scenario for moving and stationary users. Therefore, we use a simplified recursive ray tracing algorithm, which only takes into account one ray for each user per base station. Channel fading will be simulated by using Rayleigh and Rician distributed fading. To achieve a realistic Rician distributed fading, we use a variable  $k$  factor that is randomly created taking into account the respective distance

## 2 Urban environment and user mobility

### 2.1 3-D Scenario

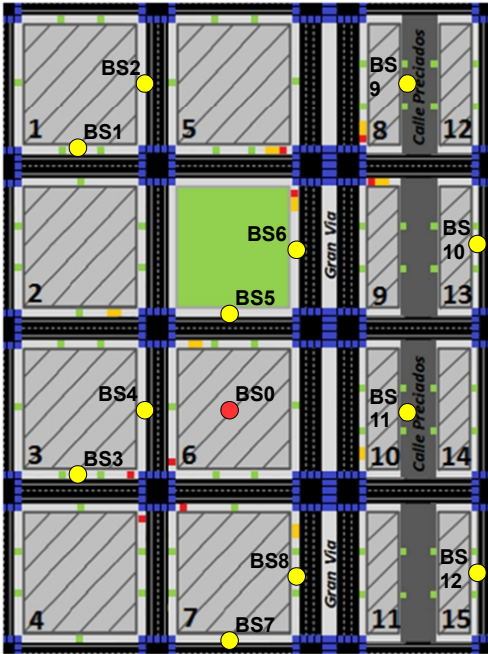
The three-dimensional scenario used in this paper is defined in ICT-317669 METIS (2013) and is called Madrid Grid scenario. This scenario consists of 15 buildings with different heights, one park area and corresponding streets between the buildings. The size of the scenario is 387 by 552 m. An overview about the scenario is given in Fig. 1.

As shown in Fig. 1, there are 13 base stations considered namely 12 microcells (yellow) and one macrocell (red). The carrier frequency is 2.6 GHz and 10 MHz have been chosen as the system bandwidth.

Each road consists of two lanes for driving and two parking lanes. The road called “Gran Via” exhibits three lanes for driving in each direction has no parking lanes.

### 2.2 User mobility

The mobility model for vehicular user is adopted from ICT-317669 METIS (2013). Here, every car moves with the



**Figure 1.** Madrid grid layout according to ICT-317669 METIS (2013).

same constant speed of 50 kmph. Changing directions is only possible at crossroads. The probability of a right or left turn is 25 % respectively, while the probability of moving straight ahead is 50 % at each crossroad.

### 3 Path loss models

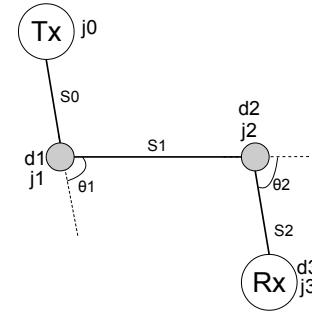
#### 3.1 Computation of macrocell path loss

In order to determine the path loss of macro cells, which are usually installed on rooftops, we use a path loss model that is proposed in ICT-317669 METIS (2013). This model takes into account the diffraction effects that radio signals experience and that is responsible for most of the signal energy received on ground level in urban environments. In this model, the calculation is divided in two parts. The first part  $L_{fs}$  describes the free space loss of signal from transmit antenna to the edge of the rooftop ( $d_r$ ) and can be calculated as:

$$L_{fs} = -10\log_{10}\left(\frac{\lambda}{4\pi d_r}\right)^2. \quad (1)$$

The second part describes the diffraction loss of the signal from the rooftop to the receiver on street and is calculated as shown in Eq. (2).

$$L_{rts} = -10\log_{10}\left[\frac{\lambda}{2\pi^2 r}\left(\frac{1}{\Theta} - \frac{1}{2\pi + \Theta}\right)\right], \quad (2)$$



**Figure 2.** Street orientation according to Berg (1995).

where

$$\Theta = \tan^{-1}\left(\frac{\Delta h}{x}\right),$$

and

$$r = \sqrt{(\Delta h)^2 + x^2},$$

$\Delta h$  represents the difference of the building height and the mobile antenna height and  $x$  the horizontal distance between the diffracting edge and the user. The resulting path loss is calculated as:

$$L = L_{fs} + L_{rts}. \quad (3)$$

Further details related to this model are shown in ICT-317669 METIS (2013).

#### 3.2 Computation of microcell path loss

In case of micro cells, which are installed below rooftop level in an urban environment, most of the signal energy reaches the user due to reflection between buildings, if the user is not in line of sight (LoS). Since tracing multiple signal reflections is computationally expensive, we choose two separate models to compute the overall microcell path loss.

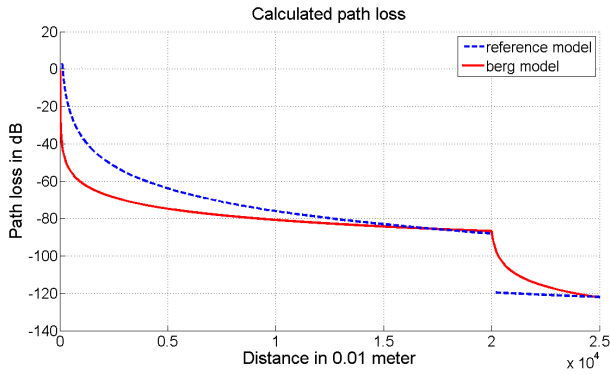
The first model is used, if the user is in line of sight and the path loss is calculated as shown in is shown in Eq. (4).

$$L_{dB} = -10\log_{10}\left(\frac{\lambda}{4\pi d}\right)^2, \quad (4)$$

where  $\lambda$  is the wavelength and  $d$  is the distance between transmitter and receiver.

The second model is employed when the user is not in line of sight (nLoS). Here, we use Berg's recursive path loss model (Berg, 1995), which takes into account geometrical conditions, such as angle of crossroads and distance between two crossroads. In principle, an imaginary distance is calculated that depends on the real distances between transmitter and receiver and the angle between two streets.

As shown in Fig. 2,  $s_1$  is the distance between crossing  $j_1$  and  $j_2$ .  $s_0$  is the distance between transmitter  $j_0$  and  $j_1$ , whereas  $s_2$  is the distance between  $j_2$  and receiver  $j_3$ . For



**Figure 3.** Calculated path loss for moving user.

the considered dense urban scenario angle  $\Theta_1$  and  $\Theta_2$  are set to  $90^\circ$ .

The imaginary distances are calculated according to Eq. (5) as described in Berg (1995).

$$k_j = k_{j-1} + d_{j-1} q_{j-1},$$

$$d_j = k_j s_{j-1} + d_{j-1}, \quad (5)$$

where  $k_0 = 1$  and  $d_0 = 0$ . The variable  $q$  represents the angle dependence of the path loss according to Eq. (6).

$$q_j = \left( \Theta_j \frac{q_{90}}{90} \right)^v. \quad (6)$$

In this case,  $q_{90}$  is set to 0.5 and  $v$  is set to 1.5 as recommended in Berg (1995). The path loss is now calculated as follows:

$$L_{\text{dB}}^{(n)} = -10 \log_{10} \left( \frac{\lambda}{4 \pi d_n} \right)^2, \quad (7)$$

where  $d_n$  is the imaginary distance between the respective transmitter and point  $n$ .

Figure 3 shows the corresponding path loss characteristic of a user moving with constant speed from point P0 to point P2 in Fig. 4. The dotted line shows the path loss of the reference model, which is further described in ICT-317669 METIS (2013) and ITU-R M.2135 (2009). The continuous line depicts the path loss of the bergs model, that is used in our approach. This approach leads to a smoother curve that may be adjusted by using the parameters  $v$  and  $q_{90}$  in Eq. (6).

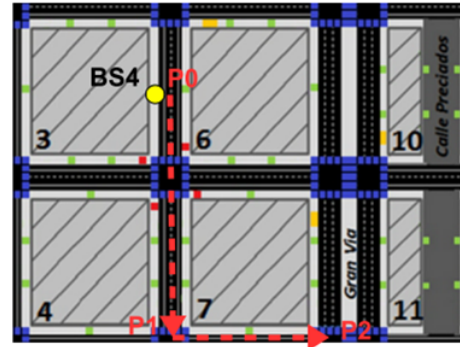
The corresponding base station is depicted in yellow in Fig. 4 as well.

As illustrated in Fig. 4 the user is in line of sight of BS4 until he reaches P2. After turning left, the user is in nLoS and the corresponding path loss model for a  $90^\circ$  crossroad is chosen.

Fading is not considered here.

#### 4 Computation of fast fading

Simulating fast fading in detail according to the three dimensional scenario including multipath propagation due to



**Figure 4.** Movement of user.

reflection, diffraction and scattering would lead to a complex model that could not be computed in reasonable time. Since we simulate numerous moving users, the fast fading will be calculated by using some statistical approaches. As suggested in Tang and Hongbo (2003), Rayleigh and Rician distributions are used to generate fast fading. In the following sections, the utilization of both models is described.

#### 4.1 Rayleigh distributed fast fading

If there is no dominant propagation path between transmitter and receiver (no line of sight) Rayleigh distributed random variables are used to describe fast fading, according to Eq. (8).

$$P_{\text{Rayleigh}}(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, \quad (8)$$

where  $\sigma^2$  represents the energy of the signal and  $r$  the magnitude. To calculate the Doppler power spectral density, we use Eq. (9), which is proposed in Kostov (2003), for the Rayleigh and Rician channel:

$$S(f) = \frac{1}{\pi f_m \sqrt{1 - \left(\frac{f}{f_m}\right)^2}}, \quad (9)$$

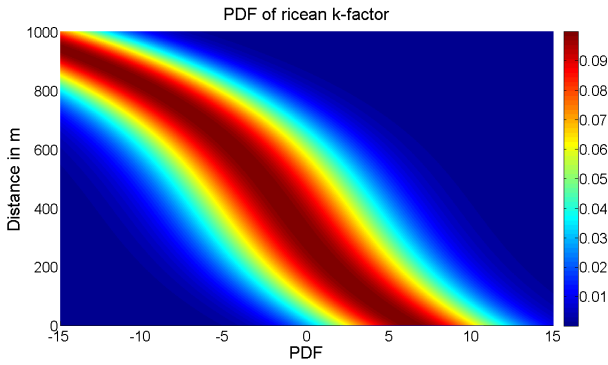
where  $f_m$  is the Doppler frequency shift that is calculated as:

$$f_m = \frac{v f_c}{c}, \quad (10)$$

$v = 50$  kmph represents the user speed,  $f_c$  is the carrier frequency, which is 2.6 GHz in this case and  $c = 3 \times 10^8$  m s<sup>-1</sup> is the speed of light. The Rayleigh fading will be pre-calculated, stored and simply added to the path loss during the simulation.

#### 4.2 Rician distributed fast fading

To simulate multipath propagation where at least one path is much stronger than the others (line of sight), we employ



**Figure 5.** PDF of the ricean  $k$  factor.

Rician distributed random variables. Rician distributed fast fading can be described as:

$$P_{\text{Rice}}(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2} + K} I_0\left[\frac{r\beta}{\sigma^2}\right], \forall r \geq 0 \quad (11)$$

with  $K = \frac{\beta^2}{2\sigma^2}$  (Jeruchim et al., 2000; Iskander, 2008).

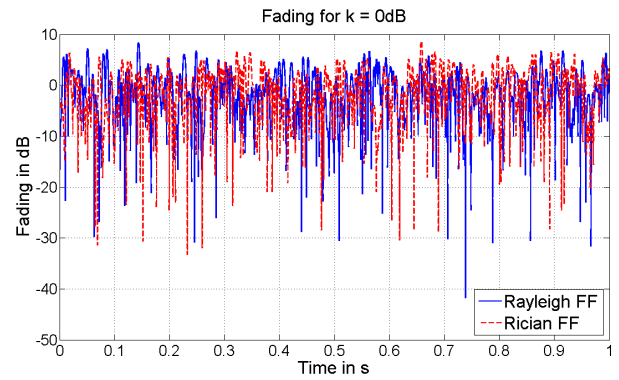
For  $K = 0$  and  $I_0\left[\frac{r\beta}{\sigma^2}\right] = 1$  Eq. (11) leads again to the Rayleigh fading calculated in Eq. (8) as proposed in Kostov (2003). The variable  $K$  is called *Ricean  $k$  factor* and rather describes the relation between the signal of the line of sight path and the non line of sight paths. As proposed in Thiele et al. (2006), the non line of sight signal components need to be summed up to determine the  $k$  factor. To avoid simulating every single signal path we use the statistical approaches to estimate the  $k$  factor, that are described in Thiele et al. (2006), Medawar et al. (2013) and Greenstein et al. (1999). In Thiele et al. (2006) and Medawar et al. (2013) functions are provided that take into account the urban environment and the distance between transmitter and receiver resulting in a cumulative distribution function (CDF) of the Rician  $k$  factor.

The  $k$  factor is now calculated using the line of sight distance from transmitter to receiver and a random value, which is generated according to the corresponding probability distribution function. Figure 5 shows the probability distribution function (PDF) of the  $k$  factor over the distance, where the  $y$  axis represents the distance in meters, the  $z$  axis stands for the probability, and the  $x$  axis shows the  $k$  factor in dB.

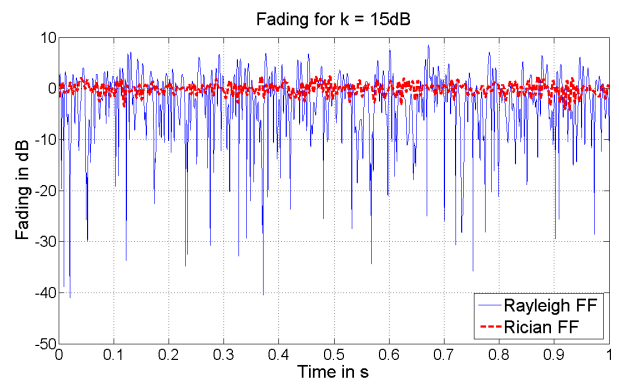
As shown in Fig. 5, the probability of a high  $k$  factor value decreases with an increasing distance between receiver and transmitter. In our simulation tool the  $k$  factor values are stored separately and used to generate Rician fading for the relevant distance between transmitter and receiver according to Eq. (11) (Jeruchim et al., 2000; Iskander, 2008).

Figures 6 and 7 show the fast fading for a  $k$  factor of 0 and 15 dB respectively.

For  $k = 0$  the Rician fading transfers into Rayleigh fading as shown in Eqs. (11) and (8).



**Figure 6.** Ricean fading for  $k = 0$  dB.

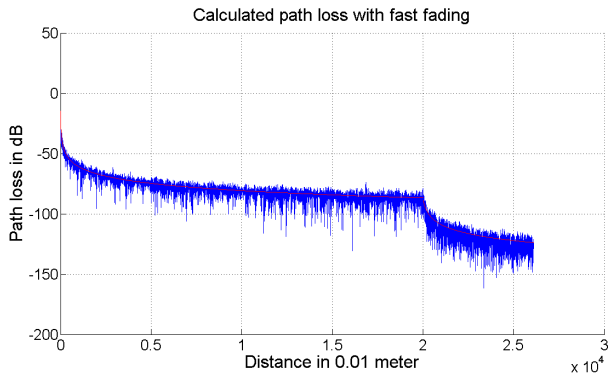


**Figure 7.** Ricean fading for  $k = 15$  dB.

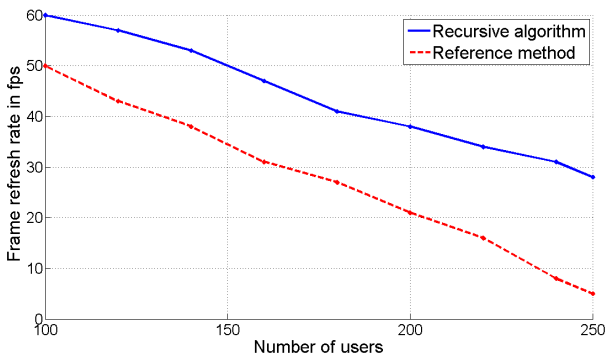
## 5 Simulation results

In this section, we will present some simulation results regarding the path loss of a moving user in the described scenario. Figure 8 shows the path loss between transmitter and a moving user that follows the same route as described in Fig. 4. The Rician  $k$  factor for nLoS conditions changes due to the distance as shown in Fig. 5. The appropriate models for fading and propagation will be chosen automatically using a single ray to detect NLoS or LoS conditions. The simulated path loss from P0 to P2 is shown in Fig. 8.

Since the main objective of this approach was to find a method that is fast enough to simulate numerous randomly distributed user in a realistic, 3-D-environment, we compare this method to a reference method, that is further described in ICT-317669 METIS (2013) and ITU-R M.2135 (2009). This method does not precompute the fading and does not use the recursive method to estimate the path loss. Further the computation of numerous log-operations is necessary here, which takes some computing time. In Fig. 9 we compare the averaged frame refresh rate during a simulation set over an increasing number of simulated users in the same scenario and the same user positions.



**Figure 8.** Path loss with fast fading.



**Figure 9.** Refresh rate vs. number of users.

As illustrated in Fig. 9 we can simulate up to 80 more users with the method proposed in this paper at a frame refresh rate of 30 fps than with the reference method.

## 6 Conclusions

In this work, we use a simplified model for efficiently computing the path loss between receiver and transmitter in line of sight conditions as well as in non line of sight conditions using Berg's recursive model. To achieve realistic simulation results we combine this model with fast fading models, such as Rayleigh distributed fading for non line of sight propagation. To consider multipath fading in line of sight conditions, we employ Rician distributed fading with a variable  $k$  factor, which depends on the distance between transmitter and receiver. The proposed model was compared with a reference model that does not use pre-computation and recursive algorithms. The model presented in this paper leads to a better performance that allows to simulate more moving users in a realistic 3-D-environment.

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