Investigation on Mobile Radio Propagation Channel Models based on Measurement Data

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Abstract. *In this paper, the mobile radio propagation channel models, obtained from software simulation and real world measurements in a multiple-input multiple-output (MIMO) system of an urban scenario (Ilmenau City) have been investigated. Our interest consists of proving the validity of the simulation model obtained, comparing the different approaches. For the comparison, the PIROPA (Parallel Implemented Ray Optical Propagation Algorithm) software and the WINNER II (Wireless world INitiative NEw Radio II) channel model have been used. The mathematical background used is the double-directional radio channel based on the on-site data. The special importance of this approach is, that not only the pathloss of the link is considered, but also the angle of departure and angle of arrival into the transmitter and receiver, are taken into account, respectively.*

Keywords

Double directional radio channel, WINNER II, channel estimation, MIMO channel, measurement data.

1. Introduction

Nowadays, wireless mobile networks are considered to be of critically importance and at the same time a major challenge for network planners, due to their increasing complexity. The systems with the highest potential are the multiple-input multiple-output (MIMO) systems, which consist of multiple antennas on both sides, i.e. transmitter and receiver. In this investigation, a linear array with 8×1 antennas at the transmitter side (Tx) and a rectangular array with 12×2 antennas at the receiver side (Rx) are used. These systems can achieve a great theoretical capacity, even though this capacity has some limits in realistic applications [1]. Such great capacity plays a main role in the wireless systems, due to the increasing amount of data required by the mobile applications. One of the models used in this study is a geometry-based stochastic model, the WINNER II model [2]. Along with the WINNER II model, an algorithm for field strength prediction called PIROPA [4] have been used. This algorithm can predict the ray paths, in a deterministic way based on the information of the transmitter and receiver position and the description of the propagation environment.

This paper is organized as follows. Section 2 describes the theoretical approach used to manage the channel modelling. Section 3 shows the measurement setup and description of the urban scenario and describes the three different approaches, used to obtain the channel model. Section 4 shows the results and comparison among the different approaches of the channel modelling. And finally, Section 5 concludes the paper.

2. Preliminary Background

The methodology used for the modelling of our channel, is based on the Double-Directional Channel Model [5]. The radio channel can be described in a single directional way, in which case the information at both ends of the path is not used. But for the double-directional channel model, the information required is the angle in both ends, i.e. at the receiver and at the transmitter end. As shown in Fig.1 the propagation channel model can be described using four parameters, $(t, \tau, \varphi_{\mathrm{RX}}, \varphi_{\mathrm{TX}})$, where, t is the time, τ is the delay, φ_{RX} is the angle of arrival at the receiver, and φ_{TX} is the angle of departure at the transmitter. The double-directional channel can be described using the following equation:

$$h(\tau, \varphi_{\mathrm{RX}}, \varphi_{\mathrm{TX}}) = \sum_{i=1}^{N} H_i e^{j\phi_T} \delta(\tau - \tau_i)\delta(\varphi_{\mathrm{RX}} - \varphi_{\mathrm{RX,i}})\delta(\varphi_{\mathrm{TX}} - \varphi_{\mathrm{TX,i}}). \tag{1}$$

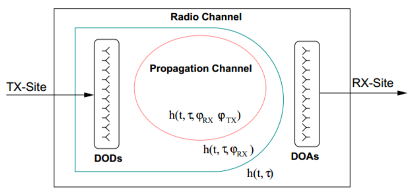

Fig. 1. Model of double directional channel [5].

In the equation 1, all the N possible paths between the transmitter and the receiver are included, and each path has its own delay determined by the parameter τ. $H_i e^{j\phi_T}$ is the time variant complex channel amplitude and δ is the Kronecker delta function.

In the transmitter side, the angle of departure (AoD) of each propagation ray has been taken into account and at the receiver side, the essential parameter is the angle of arrival (AoA) for each ray. The main characteristic of this approach, it is showing which direction of arrival (DoA) corresponds to the respective direction of departure (DoD) at the transmitter, i.e. the angles are paired, and it also gives us the channel weights of each path independently. To conclude, both DoD and DoA can be tracked back to the scattering objects from both sides, making it possible to obtain the complete propagation path.

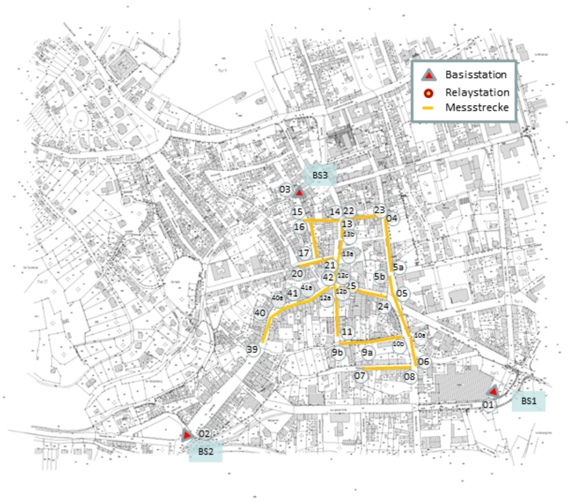

Fig. 2. Map of Ilmenau city indicating the positions of the BS and the measured paths.

3. Channel Modelling

In this section, the channel modelling of the scenario is made using three different sources: directly from the data collected in the measurement campaign of the Ilmenau city, using the PIROPA deterministic algorithm and a theoretical approach using the WINNER II stochastic channel model. The differences among these three approaches are based in the nature of them. On one hand, the Ilmenau approach is based on the data acquired by the channel sounder during the measurement campaign, along with the information of the antenna arrays. On the other hand, the PIROPA algorithm, is a deterministic one, that is, for the same input and parameters, the output will be always the same. Finally, the WINNER II is a stochastic model with two levels of randomness, i.e. the large scale parameters, such as shadow fading, angular and delay spreads. The second level of randomness, is due to the small scale parameters, like delays, powers and directions of arrival and departure at both sides.

Antenna in BS	RUSK HHI 8x1 PULA
Antenna in MS	RUSK HHI 12x2 SPUCPA CUBE
Carrier frequency	2.53 GHz
Bandwidth	100 MHz
Transmission power	0 dB

Tab. 1. Antenna array setup at both ends.

3.1 Ilmenau Data

The scenario used for this channel modelling is Ilmenau city, Germany [3]. The scenario is a pedestrian zone in Ilmenau with a medium density of buildings, which are not higher than five floors. Three base stations were displayed in a triangular form, covering the center of the city and a relay settled in the middle of it. With this configuration, the paths are mostly in a NLOS (Non- Line Of Sight) situation and only in a few paths are in a LOS (Line Of Sight) environment. The Fig.2 shows the scenario, which can be determined as an outdoor one with an average distance between the mobile stations and base station of 1.5 kilometers. The paths are measured using an antenna array on top of a car travelling at a constant speed and the base station antennas are situated at 50 meters over the street. The antenna arrays used for the base and mobile stations are shown in Tab.1.

At the transmitter side, the antenna array (RUSK HHI 8x1 PULA) is an uniform linear array with 8 dual-polarized (Horizontal/Vertical) elements, each one consists of 4 patches to narrow the beam. At the receiver side a circular array (RUSK HHI 12x2) with 2 rings of 12 patches with (Horizontal/Vertical) polarizations is settled. From the Ilmenau data, the most significant paths of the city are used, as a representative sample of the behavior of all paths. These paths are the ones located in the center of the city and exhibiting all the different multipath phenomena. For each path, the position and rotation in the receiver and in the transmitter positions, as well as the power and delay in the receiver side are known. Using these data the channel model could be obtained and the profile of the channel can be calculated. The city was divided into segments with an average of 100 meters and an average speed movement of the mobile stations, of 4 meters per second.

3.2 PIROPA

The PIROPA software calculates the propagation paths by following the rays lauched at the Tx antenna. Each deflection and difraction at the lauched rays are calculated explicity, following ray optics. For the PIROPA software, the positions of the transmitter and the receiver have to be introduced into the algorithm, and with them, the attenuation

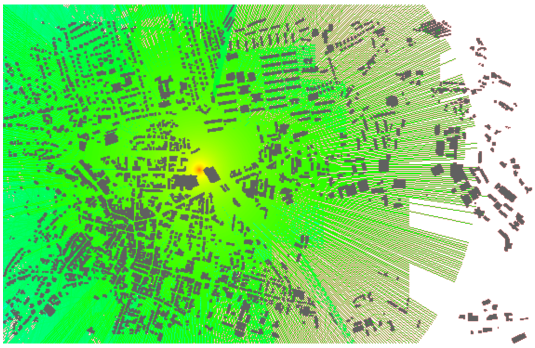

Fig. 3. Resulting map of the rays prediction using PIROPA.

of the path, the AoA and AoD for each path are obtained. Finally, for the prediction of the field, scenario architecture, namely, the building and other elements of the city, are required, thus an input parameter of the building structures and the rest of the environment elements of the city have to be added [4]. After introducing the input data of the transmitter and receiver and the city scenario, the algorithm creates a tree structure, where in each node the transmitter is represented. Each node has branches that represent the different groups of rays and reach to the final point (leaves), i.e. the receiver. Receivers will correspond to several leaves, since we are dealing with a multi-path environment. As shown in Fig.3, one of the possible outputs only for the strongest paths, where each pixel represent a receiver.

3.3 WINNER II Channel Modelling

WINNER II model specifies a number of scenarios such as indoor office, urban microcell, suburban, urban-macro cell and rural macro cell. For the simulation of channel modelling using WINNER II, the scenario is fixed as an urban-macro cell [2], where the mobile station are located outdoors at street level and the base stations are located above the buildings, in our case, the base stations are located 50 meters over the floor level. The WINNER channel modelling process is divided into three phases. The first part begins using the propagation scenarios definition, i.e. selection of antenna heights, mobility, selection of environment to be measured and other general requirements. The second phase concentrates in the data analysis, where depending on the required parameters, different analysis methods are applied. The third phase convers the item required for simulation, in this phase the MIMO transfer matrix is obtained.

The WINNER II channel model used is a geometry based stochastic model, in which the propagation parameters and the receiver and transmitter antennas can be considered separately. Using the PIROPA output, some of the parameters of the WINNER II channel model can be replaced, instead of calculating them in a stochastic way. The parameters of this channel modelling are : (τ, P, AoA, AoD), where τ, is the delay, P is the power, AoA is the angle of arrival

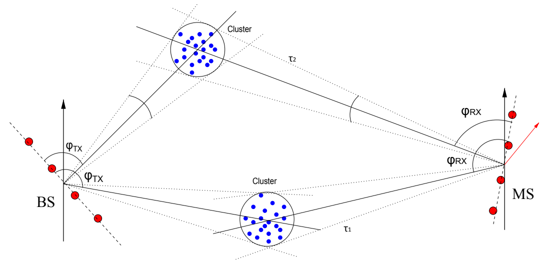

Fig. 4. Geometry-based stochastic MIMO channel model.

and AoD is the angle of departure. The propagation environment is formed by a number of propagation rays, which are grouped in cluster, see Fig.4. These clusters are generated randomly based on some stochastically properties and within each cluster there is a group of rays.

4. Results

The measured data has a spatial resolution of 0.1 meters. When comparing to the other models, a down sampling is performed, in order to obtain the same spatial resolutin as the other models. The pathloss calculated with the three different approaches shows a similar behavior in general terms, however, as noted in Fig.5, the prediction given by the WINNER channel model displays high fluctuations, where the minimum values are underneath the other simulations. The behavior shown using the PIROPA algorithm is different, this is caused by the format of the data, since the data is clustered in function of the delay, which takes us to a less abrupt profile. Nevertheless, the average power given by the PIROPA algorithm coincide with the average power both the Ilmenau data and with the WINNER II model. The different peaks, as shown in the Fig.5, are caused by the multipath properties of the environment which lead to a constructive interference in some cases and destructive ones in others. These peaks are not shown in the PIROPA profile, due to the presence of clustered data, which eliminate the peaks giving us the average power. For comparison, the data in Ilmenau and WINNER II model have been smoothed, in order to be able to compare them with the PIROPA algorithm. Moreover, the pathloss in PIROPA algorithm might be not totally suitable for Ilmenau city, due to it has been created using a different scenario. To sum up, the pathloss power is calculated from 40 samples of an entire representative path, which shows the general environment behavior of the complete scenario.

In this work, a different way of data clustering is used, i.e. the K-means algorithm. For this algorithm, the data from a complete path is used and clustered in function of the delay, with a cut-off value of 0.1 microseconds. Using the K-means algorithm the clusters will be defined [6]. The algorithm is based on the following: the first step selects K centers randomly. The next step consists on moving the data to the nearest center (minimum Euclidean distance). The

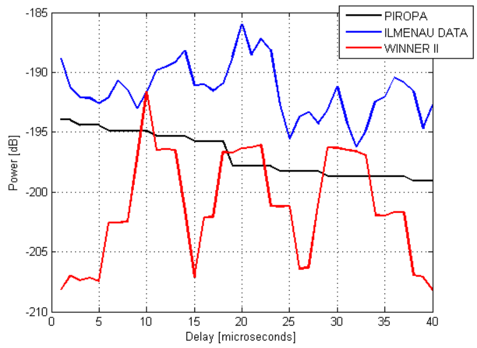

Fig. 5. Comparison of pathloss among the three approaches for one path using moving averages.

Euclidean distance is used to determine the distance among the data points and the centers chosen before. After that, all the points have to be grouped into a determined cluster. The following step consists on recalculate the centers and recursively calculate the distance, in case of the presence of a closer center, the data is moved towards it. The algorithm continues, until all the distances are minimized and all the data points are forming a cluster. For the K-means algorithm the following expression for the euclidean distance is used:

$$d(x_i, y_i) = \left[\sum_{i=1}^{N} (x_i - y_i)^2 \right]^{1/2} \tag{2}$$

where d is the resulting euclidean distance, x is the position of the centers, y is the position of the measured data and N is the number of different measured points. As shown in Fig.6, the data points are forming a determined number of clusters in function of their delay and power.

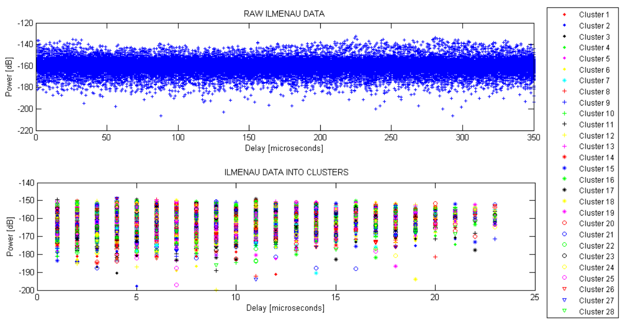

Fig. 6. Clustering of data using K-means as function of the delay and power.

The K-means algorithm always converges to a local minimum. The time of calculation depends on the initial position of the centers, which can be randomly selected although the best position of these centers can be obtained by making some previous calculations. In the following Tab.2, the resulting different number of clusters using several approaches is given.

Clusters in function of the delay	**44**
Clusters using PIROPA algorithm	**34**
Clusters using K-means in Ilmenau data	**28**
Clusters using WINNER II	**40**

Tab. 2. Number of cluster obtained using different algorithms

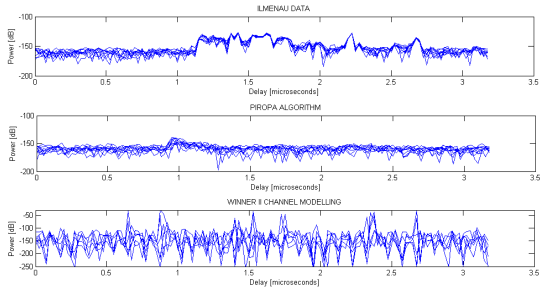

Fig. 7. Power delay profile using three different approaches.

As shown in Fig.7, the power delay profile of a representative path of the Ilmenau city data is displayed. The highest power peaks occurred, in the range of delay between 1 and 2 microseconds, where the constructive interference made by the reflections in the buildings and the street appears. In the rest of the profile, the signal is not higher than the previously calculated noise of -150 decibels. As is shown in Fig.7, the profile in the first two approaches, i.e. Ilmenau data and PIROPA, is similar. The PIROPA algorithm, underestimates the power received at the receiver, which can be seen in the number of high power peaks displayed, compared to the Ilmenau power profile. For the WINNER II channel model, the power follows a different profile, because this model does not take into account the propagation envorinment, giving a random profile.

5. Conclusions

The results of our analysis, indicate that using PIROPA software, an approximation of the true behavior of the channel is obtained, but because of the multiple factors that are involved in the channel estimation the prediction is not completely accurate. One factor which has been of major importance, is the algorithm of clustering for the path rays. Different methods have been used, i.e. K-means and in function of the delay, and these methods lead to a similar value, as the predicted one using the PIROPA algorithm. Finally, the power-delay profile in Fig.7 using the PIROPA algorithm, shows a similar result compared to the Ilmenau results, not as in the WINNER II channel model where the profile is different and the number of power peaks is far greater.

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References

[1] GOLDSMITH ANDREA, JAFAR SYED ALI, JINDAL NIHAR. ”Capacity Limits of MIMO Channels”. *Journal on Selected Areas in Communications*, 2003, vol. 21, no. 5, p. 684 - 702.

[2] IST-WINNER II D1.1.2 V1.2 ”WINNER II Channel Model IST-4-027756,” 2007, http://www.ist.winner.org

[3] SCHENEIDER CHRISTIAN, NARANDŽIC MILAN, KÄSKE MARTIN, HONG AIHUA, SOMMERKORN GERD, ALGEIER VADIM, KOTTERMAN W.A.Th., THOMÄ REINER S., JANDURA CARSTEN. ”Multi-User MIMO Channel Reference Data for Channel Modelling and System Evaluation from Measurements”.

[4] SCHRÖDER FLORIAN, REYER MICHAEL, MATHAR RUDOLF. ”Field Strength Prediction for Environment Aware MIMO Channel Models”. *In Proceedings of the 6th European Conference on Antennas and Propagation (EUCAP)*, 2011, p. 2384 - 2387.

[5] STEINBAUER MARTIN, MOLISCH ANDREAS F., BONEK ERNST. ”The Double-Directional Radio Channel ”. *IEEE Antennas and Propagation Magazine*, 2001, vol. 43, no. 4, p. 51 - 63.

[6] NA SHI, XUMIN LIU, YONG GUAN. ”Research on k-means Clustering Algorithm. An Improved k-means Clustering Algorithm”. *In Proceedings of the Third International Symposium on Intelligent Information Technology and Security Informatics*, 2010, p. 63 - 67.