A Validation using Measurement Data of a Radio Channel Model with Geographical Information

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Abstract—**The wireless channel in mobile communications changes the transmitted signal and thus must be properly modeled. If a multiple-input multiple-output (MIMO) system is considered, the modeling procedure becomes more challenging. In this paper, a novel radio channel model is implemented and validated using measurement data. On one hand, statistical properties of MIMO channels are modeled by geometry-based stochastic models, such as the WINNER II model. On the other hand, the physical phenomena of radio wave propagation can be described by deterministic methods, such as PIROPA (parallel implemented ray optical propagation algorithm). Additionally, the proposed channel model can be derived by combining the stochastic model and physical model. The results show that the proposed channel model has advantages in modeling accuracy and execution time over the WINNER II model.**

Index Terms—**radio channel model, measurement data, MIMO, ray-tracing, outdoor propagation**

I. INTRODUCTION

In the recent years, a high number of mobile networks has been deployed. The importance of these networks increases every day because of the multitude of applications in the daily life. Hence, it is essential to have a better understanding of wireless networks by modeling them.

Outdoor mobile networks have been modeled during the past years using different approaches, e. g., deterministic or stochastic models. Deterministic models have the advantage of a high reliability due to the use of input information from the scenario. In contrast, deterministic models have a high computational complexity which makes them inappropriate for real time applications. The stochastic channel models have been proven to be sufficiently fast in computational terms to be applied for real time applications, but they have a lower accuracy compared to the deterministic models.

In this paper, a different approach is proposed, combining the finest from the two previous channel models. This approach is considerably faster than the pure deterministic methods, and it also has higher accuracy in its results. For the deterministic part, a ray-launching algorithm (PIROPA) [1] is used, and the stochastic part is modeled using the WINNER II model [2]. This model is computed in MATLAB, in order to obtain the output for comparison with measurement data gathered during a measuring campaign on site.

The outline of this paper is as follows: Section II illustrates the measuring campaign and the obtained measurement data. Section III introduces the proposed radio channel model and the different parts forming it along with the implementation. Section IV presents the results of the model created and the comparison with the measurement data. Section V concludes the paper.

II. MEASUREMENT CAMPAIGN

The measurement campaign was operated by the Ilmenau University. During the measurement campaign, three different base stations were deployed around the city, forming a triangle and 42 outdoors paths were analyzed [3].

The measurements were performed simulating a pedestrian moving at 1.5 m/s, prevailing in the measurements a situation of wide-sense stationary uncorrelated scattering (WSSUS), due to the invariance of the channel parameters in the short term [4]. The antenna patterns were as follows: at the transmitter side, a directional beam with a 30 degree amplitude and at the receiver side, an omnidirectional pattern to optimize the received information. The base stations were at a height of 50 meters above the ground level and the mobile stations were composed by an antenna array located on top of a car.

The frequency of the measurements takes place in the range of 2-3 GHz, in order to emulate 3G and LTE measurements. The channel sounders, RUSK TUI-FAU, were designed by Medav Company, Germany [5]. Using these sounders the measurements of the MIMO channel were obtained in time and spatial domain.

III. RADIO CHANNEL MODEL

The radio channel model implemented in this study is created combining a pure deterministic algorithm (PIROPA) and a stochastic channel model (WINNER II). The main goal of this implementation is to obtain a highly reliable radio channel and at the same time, a less time consuming model for real time application.

A. PIROPA Algorithm

The first part of the model developed in this paper is the deterministic part created using a ray-lauching algorithm. In order to execute PIROPA, the geographical data of the scenario is required along with the position of the base and mobile stations. Using PIROPA, the assumption that base stations are static is a requisite and only one propagation scenario per base station is calculated at the same time.

Once the location of the elements of the network is settled, the ray-lauching algorithm calculates the channel properties of every link between the transmitter and the receiver with a granularity of 1 meter.

The algorithm can be considered as rays being radiated through infinitesimal small tubes, called rays, which are normal to the surface. The propagation method is based on refractions and reflections considering the obstacles as vertical surfaces, neglecting other forms. Each ray, that is launched, can be traced back using a tree, where the surface of impact of the obstacle is treated as a node in the tree. This algorithm continues monitoring the rays until the ray reaches its destination, or the power of the ray is weaker than an estimated power threshold, caused by the different bouncing off objects.

B. WINNER II Model

The WINNER II model is a Geometry-Based Stochastic Model (GBSM) which models the channel using stochastic properties. Using the WINNER II model, the radio channel and antennas at both sides of the radiolink can be treated independently. The channel parameters are generated stochastically based on statistical distributions extracted from the channel measurements [6]. The rays in WINNER II channel model are grouped into clusters which are defined like a propagation path diffused in space and delay, into the same angle domain.

In the WINNER II channel model, the MIMO transfer matrix, $\mathbf{H}(t;\tau)$, is as follows:

$$\mathbf{H}(t;\tau) = \sum_{n=1}^{N} \mathbf{H}_n(t;\tau) \tag{1}$$

where N is the number of clusters as defined before and τ is the time delay. If the antenna arrays at both ends of the link are included, the transfer matrix changes to introduce these values as follows:

$$\mathbf{H}_n(t;\tau) = \int\int \mathbf{F}_{Rx}(\varphi)\mathbf{h}_n(t;\tau,\phi,\varphi)\mathbf{F}_{Tx}^{T}(\phi)d\phi d\varphi \tag{2}$$

where $\mathbf{F}_{Rx}(\varphi)$ is the antenna pattern of the receiver antenna, $\mathbf{h}_n(t;\tau,\phi,\varphi)$ is the impulse response of the multipath channel and $\mathbf{F}_{Tx}^{T}(\phi)$ is the antenna pattern of the transmitter antenna.

The generic model of WINNER II is a stochastic model with two level of randomness. The first level of randomness is formed by a large scale (LS) parameters, e. g., shadow fading and delay spread, among others. The second level is the one formed by the small scale (SS) parameters, e. g., delay, power and direction of arrival and departure.

C. Proposed Radio Channel Model Implementation

The implementation of the proposed radio channel model is made in MATLAB. The main goal is an adequate model for outdoor propagation that is fast enough to be used for real time applications. This model combines the best qualities from both models: from the ray-launching algorithm the level of detail and the accuracy, and from the stochastic model the quickness of execution and generation of random parameters. The channel model can be defined as a semistochastic channel model [7], due to the combination of random and deterministic parameters.

The implementation of this radio channel is based on the assumption that the clusters, as defined in WINNER II, are equivalent to the ray paths in PIROPA. Under this assumption the radio channel is created using the output parameters from PIROPA, and introducing them as inputs, in order to generate the stochastic parameters for WINNER II.

IV. RESULTS & VALIDATION

In the present section, the results obtained from the proposed radio channel model, their comparison with the WINNER II channel model and the data obtained from the measurement campaign are presented. The parameters here published are the most representative of the channel characteristics and they show the accuracy of the proposed radio channel model.

A. Received Power

The received power is the main parameter of the propagation environment. It is crucial in the design of a network, because it shows the maximum coverage of a base station within a established power threshold. It presents the power at the receiver after the multipath phenomena occur. Due to the different bouncing off the obstacles presented in the environment, the received power is not only dependent of the distance as is expected from the following formula:

$$ReceivedPower(d) = Power(d_o) + 10\gamma\log(\frac{d}{d_o}) \tag{3}$$

where γ parameter defines the relationship between the separation distance and the received power [8]. The received power is calculated in decibels in Eq. (3). In the case of a multipath scenario, the multiple scatters play a major role in the propagation profile creating destructive, or in some cases, constructive interference into the received power, as shown in Fig. 1. Therefore, the behavior of the received power is highly dependent of the fading created by the obstacles, thus an stochastic behavior is shown.

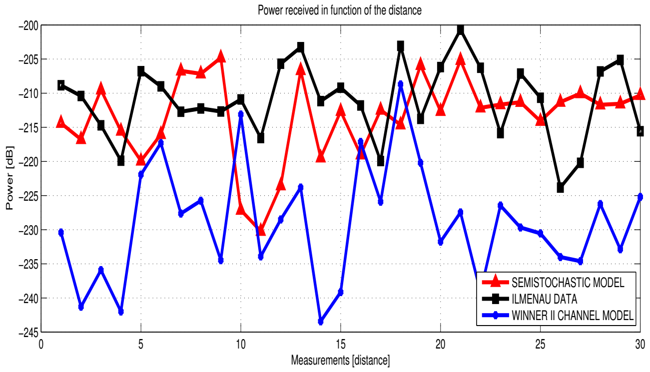

Fig. 1. Received power in a multipath scenario

The resulting output, Fig. 1, shows a greater accuracy in the semistochastic channel model than in the WINNER II channel model compared using the data obtained on site. The greater accuracy of the proposed channel model shows the importance of the knowledge of the propagation scenario.

The MSE (Mean Square Error) obtained for the semistochastic channel model is $\sigma_{MSE_{semi}}$= 4.12 dB while in the case of the WINNER II channel model is $\sigma_{MSE_{win}}$= 12.73 dB. In this case the difference between results is substantially wide enough to consider the proposed model as a reasonable improvement respect to the WINNER II channel model.

As shown in Fig. 1, the profile of WINNER II channel model has very big oscillations and does not follow the measurement data profile. The mismatch between both profiles is because the WINNER II channel model has no information about the scenario, and it is only based on distance and statistical distributions. In contrast, the proposed channel model has geographical information, which makes it more sensitive to the changes in the scenario environment.

B. Power Delay Profile

The next analyzed parameter is the power delay profile (PDP), which defines the received power of the different rays in function of the delay reaching at the receiver side. The degree of dispersion of the rays caused by multipath is evaluated by the power delay profile. The highest power received, as expected, is at 0 ms delay, which corresponds to the non-delay scenario. The rays in a Line-of-Sight (LOS) condition have no delay and, therefore, they do not suffer from multipath propagation [9]. The rest of the rays suffer from this phenomenon and their power is attenuated due to the scatters and the higher distance traveled as shown in Fig. 2.

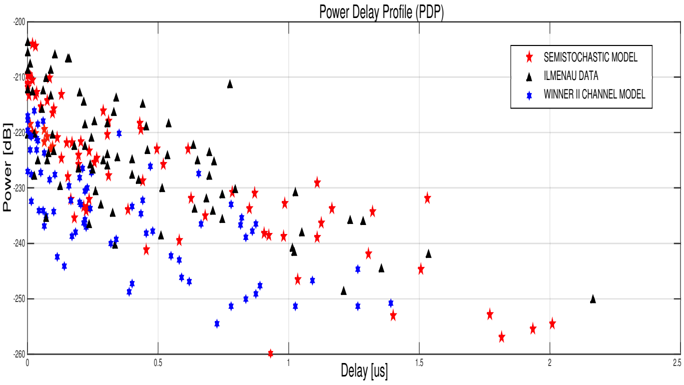

Fig. 2. Power Delay Profile of a multipath scenario

In Fig. 2, the proposed channel model has a similar behavior compared to the measurement data, being in the same range of power and delay. The WINNER II channel model has a worse behavior compared to the proposed channel model, having differences up to 20 dB with the reference data. The difference in the results is caused mainly by the lack of scenario information in the WINNER II channel model, which causes a mismatch in the multipath propagation created by the different scatters.

As shown in Fig. 2, the range of the delay spread between the proposed semistochastic channel model and the measurement data is comparable. The delay spread is of major importance at the receiver side, because it gives us an idea of the time needed to decode a received frame. Moreover, using this value, different techniques to avoid interference between received frames can be applied.

C. Angle of Arrival

The next parameter analyzed is the Angle-of-Arrival (AoA) at the receiver side. The AoA is an essential parameter to describe the accuracy of the deterministic ray-launching algorithm. Using this parameter, the different propagation effects on scatters can be validated and it can be used to orient the antenna into the direction with the highest concentration of received rays. In addition, in future applications knowing the AoA, the receiver antenna can be controlled to modify its direction, so the received power at the antenna is optimized. As shown in Fig. 3, the proposed model has a very similar profile, only having a small deviation from the measurement data.

The AoA obtained from the measurement campaign, has been calculated at the receiver side using the channel sounders and determining the exact points where the rays are received. The WINNER II channel model fails at modeling this particular parameter because of the insufficient information about the scenario scatters in this model. As seen in the graphical results, the deterministic ray-launching algorithm is able to model the propagation scenario accurately, therefore, the final parameters will be precise enough to validate the channel model.

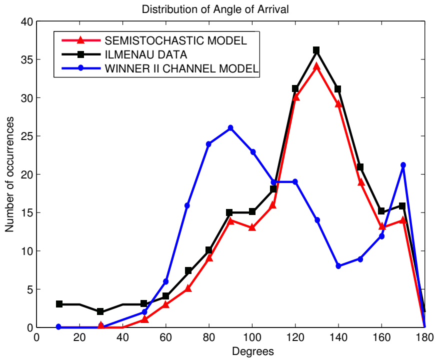

Fig. 3. Distribution of Angle of Arrival at the receiver side

D. Capacity

Capacity is the upper bound of information that can be transferred through the communication channel [10]. This parameter characterizes the channel, giving the best behavior of it. The capacity depends linearly on the frequency, because the higher the frequency, the higher the amount of information that can be transported [11].

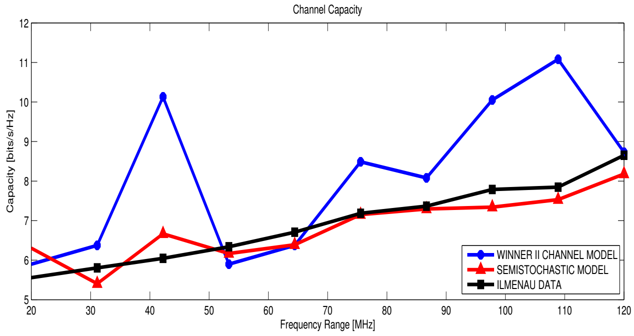

Fig. 4. Capacity of the radiolink in a multipath environment

As shown in Fig. 4, the capacity calculated by the proposed channel in this paper is similar to the one obtained from the measurement data, while the one calculated using WINNER II diverges in a considerable sum. The similarity of the capacity in the proposed channel model is the result of the accuracy in the rest of parameters calculated, and it is the concluding parameter to verify the proposed radio channel model.

E. Time consumption

The last parameter mentioned is the time consumption during the execution of the channel model.

Channel Model	Execution Time	Accuracy
WINNER II	480.3 s	Medium
Proposed model I	830.7 s	High
Proposed model II	181.2 s	High

TABLE I
COMPARISON OF EXECUTION TIME FOR THE DIFFERENT MODELS

As shown in the table I, the execution time is compared between the WINNER II channel model implementation and two different executions of the proposed model. The execution time depends in both cases on the number of receiver point placed in the network to simulate. In our execution, a receiver was placed in a path with a granularity of 1 meter.

For the WINNER II model, the complete execution is needed to be calculated every time, which can lead to a very time demanding operation. In contrast, the execution time of the proposed model is divided in two, e. g., a very demanding time and memory first part, which is needed to be executed only once per base station and scenario. The second execution, once the deterministic parameters are calculated, consists on the execution of the semistochastic channel model using PIROPA, along with the generation of stochastic parameters using WINNER II channel model. The second part of the execution scheme, as shown in Section IV-E, is way faster compared to the WINNER II model, providing a better management of resources and time, due to its parallel architecture.

Even when the first execution of our proposed channel model is really time demanding, as being needed to execute it only once, the overall improvement in the execution time is considerable and it is an advantage of our model compared to WINNER II.

V. CONCLUSION

This paper presents the implementation and validation, using measurement data obtained on site, of a proposed radio channel model. The novelty of this channel model is the combination of a deterministic algorithm and a stochastic channel model. The channel model has been validated comparing the main characteristic parameters of a multipath scenario and showing that the accuracy is higher than other widely used models such as, WINNER II channel model. The requirement for the proposed channel model is to obtain the geographical information of the scenario, including all the scatters.

Moreover, it has been shown that the execution time of the proposed model is appreciably inferior than the WINNER II model, making it suitable for real time applications.

In further investigations, new features will be added to the radio channel model granting a better modeling of the channel, e. g., cluster algorithms, mobility scenarios and inclusion of different multipath scenarios.

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REFERENCES

[1] Florian Schröder, Michael Reyer and Rudolf Mathar, *Field Strength Prediction for Environment Aware MIMO Channel Models*, 6th European Conference on Antennas and Propagation (EUCAP), 2012.

[2] IST-WINNER D1.1.2 P. Kysti, et al., ”WINNER II Channel Models”, ver 1.1, Sept. 2007. Available: https://www.ist-winner.org/WINNER2-Deliverables/D1.1.2v1.1.pdf

[3] Aihua Hong, Gerd Sommerkorn, Reiner Thoma and Wolfgang Zirwas, *Considerations on the relationship between path loss and spatial characteristics based on MIMO measurements.* Available: http://www-emt.tu-ilmenau.de/EMTPub/uploads/pdf/53R26L34LN40.pdf

[4] Molisch, A.F., Kuchar, A., Laurila, J., Hugl, K., Bonek, E., *Efficient implementation of a geometry-based directional model for mobile radio channels*, Vehicular Technology Conference, 1999. VTC 1999 - Fall. IEEE VTS 50th.

[5] http://www.medav.de/medav_home.html

[6] Kermoal, J.P., Schumacher, L., Pedersen, K.I., Mogensen, P.E., Frederiksen, F., *A stochastic MIMO radio channel model with experimental validation*, Selected Areas in Communications, IEEE Journal on (Volume: 20, Issue: 6), 2002.

[7] Xiang Xu, Michael Reyer, Florian Schröder, Alexander Engels and Rudolf Mathar, *A Semi-Stochastic Radio Propagation Model for Wireless MIMO Channels*, International Symposium on Wireless Communication 2011.

[8] Sarkar, T. Wicks, M., Salazar-Palma, M., Bonneau, R., *A Survey of Various Propagation Models for Mobile Communication*, Wiley-IEEE Press, 2003.

[9] W. Weichselberger, M. Herdin, H. Ozcelik, and E. Bonek, *A stochastic MIMO channel model with joint correlation of both link ends* to appear in IEEE Transactions on Wireless Communications, 2005.

[10] Ozcelik, H., Czink, N., Bonek, E., *What makes a good MIMO channel model?*, Vehicular Technology Conference, IEEE 61st, 2005.

[11] Sarkar, T. Goldsmith, A., Jafar, S.A., Jindal, N., Vishwanath, S., *Capacity limits of MIMO channels*, Selected Areas in Communications, IEEE Journal on (Volume: 21, Issue: 5), 2003.