APPROACH FOR MIMO WIRELESS CHANNEL MODELLING AND SYSTEM CHARACTERIZATION

Michail Malamatoudis
Technological Educational Institute of Eastern Macedonia and Thrace, Greece

Abstract
While coding and signal processing are key elements to successful implementation of a MIMO system, the communication channel represents a major component that determines system performance. There are a variety of different approaches used for modelling the MIMO wireless channel. This paper is focus on modelling aimed at characterizing the MIMO channel spatial-temporal properties. The approach discussed in this paper is defined to include the electromagnetic propagation and antennas, although different modelling techniques may include all or only part of this set.

Keywords: Channel model, Indoor environment, MIMO, Wireless coverage

INTRODUCTION

A site-specific channel model can be created using information about the environment and the radio propagation model. The main purpose of the modelling is to obtain the specific channel information for a given scenario. Well-known site-specific channel models are the methods based on electromagnetic propagation such as finite difference time-domain and ray-based methods. One of the main applications of such models is the deployment of wireless networks and the planning of radio coverage in indoor and outdoor environments. A particularly suitable for purpose is the ray-tracing method due to the modelling efficiency [2,3].

Wireless network planning and optimization is the one of the major applications of the site-specific channel models [4,5,6]. To optimize the locations of the network nodes, such as base station, a large number of potential locations are predicted, which is computationally demanding. Therefore, for the application of network deployment and optimization, a computationally efficient channel model is highly desirable.

The purpose of the paper is to propose simulations using 2 ray-tracing based models in MIMO channel modelling for indoor wireless network deployment application. The first ray-tracing model is a direct application of ray-tracing to MIMO modelling. The second model based on probabilistic principle. Furthermore, the comparison between the model simulation results and channel measurements shows good agreements.

A ray-tracing model is suitable because it can provide multipath information, and therefore it can be used for modelling various channel parameters in multipath channel condition.

This work verified the simulation results with measurements in an indoor scenario with a 2 × 2 MIMO system – fig. 1. Fig. 1 depicts a generic MIMO system that will serve as a reference for defining the MIMO channel, where Q is a stream of vector input symbols, N_T – the number of transmit antennas, N_R – the number of receive antennas, and H – the matrix element, which is characterized the channel between the transmitter and the receiver.

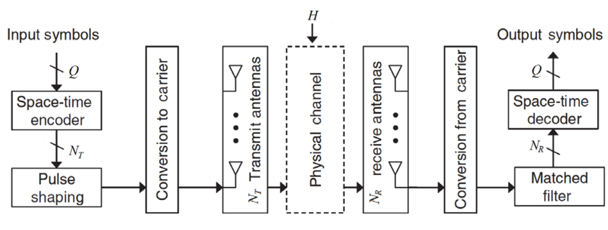


Fig. 1. *Generic MIMO communication system*

MODELING OF INDOOR MIMIO CHANNEL

Deterministic model

The MIMO system is to equip multiple antennas at both the transmitter and the receiver – fig. 2.

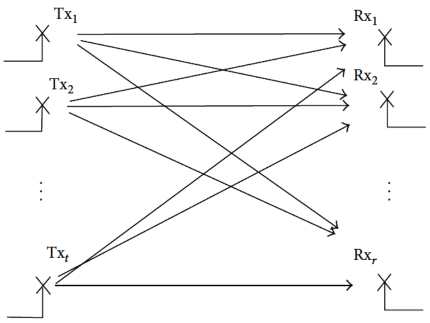


Fig. 2. *MIMO transmitter and receiver scheme*

The transmitter is equipped with a t-element antenna array and the receiver is equipped with a r-element antenna array. The MIMO channel is then written in the form of matrix as follows:

$$CH = \begin{bmatrix} CH_{1,1} & \cdots & CH_{1,r} \\ \vdots & \ddots & \vdots \\ CH_{t,1} & \cdots & CH_{t,r} \end{bmatrix} \quad (1)$$

The matrix element $CH_{m,n}$ characterizes the channel between the transmitter element n and the receiver element m.

We assume the MIMO channel is narrow band throughout the paper. According to multipath propagation, the narrow band MIMO channel matrix elements can be written as

$$CH_{m,n} = (x, y, z, \omega) = \sum_{\alpha=1}^{q} G_{\alpha}(x, y, z) e^{-j\omega_0 \tau_{\alpha}(x,y,z)} \quad (2)$$

where G_{α} is the amplitude of the α-th ray, q is the total number of rays, τ is the time delay and τ_{α} is the delay of the α-th ray, and ω_0 is the carrier frequency.

This equation gives the channel frequency response as a result of summation of the rays or multipath components. It is the mathematical relationship we use to obtain the channel from the ray-tracing model. To obtain a complete set of MIMO channel matrices of the network deployment site, the prediction is repeated over the locations of the deployment site, until the set of locations (x, y, z) covers the deployment site. Fig. 3 shows an example of ray-tracing model in an indoor single room environment.

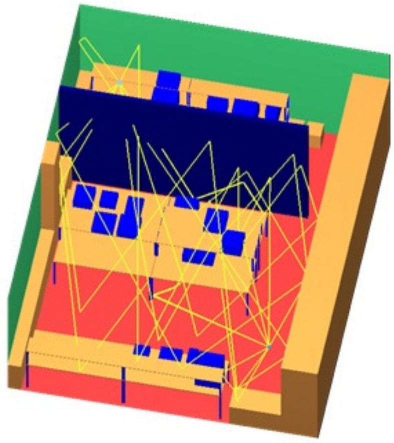


Fig. 3. *Ray-tracing in an indoor environment*

Statistic model

Modelling the wireless channel as a probabilistic fading channel is another category of channel models in contrast to the deterministic channel models [3,7]. It has the advantage of simplicity and efficiency when physical model is prohibitively complex. We propose a probabilistic channel model for MIMO based on the ray-tracing model. Considering that the model is specifically for indoor scenario, we model the fading channel as Rician distribution, because it comprises a rich group of probability distributions: by determining various values for the Rician K factor, a group of statistical distributions is included. The ray-tracing model supplies the multipath information to estimate the parameters for the Rician distribution.

We model the channel matrix element $CH_{m,n}$ in Eq. 1 as a Rician distributed random variable:

$$CH_{m,n} \approx Rice(v, \sigma) \quad (3)$$

where v and σ are the parameters to determine the Rician distribution.

The ray-tracing model traces a group of rays equivalent to the multipath components. This multipath information can be used to estimate the parameters of the Rician distribution. Below we adopt the method from the work of [1] to estimate the Rician distribution parameters. According to [1] the K-factor in Rician distribution can be estimated as:

$$K = \frac{\sqrt{1-g}}{1-\sqrt{1-g}} \tag{4}$$

The variable g in Eg. 4 is given as $g = V[G^2]/(E[G^2])^2$, where V[G^2] is the variance of G^2 (G is the amplitude of the ray field), and the E[G^2] is the expected value of the G^2.

After value of K-factor is obtained, the Rician distribution parameters v and σ can be easily calculated:

$$v^2 = \frac{K.\Omega}{1+K} \tag{5}$$

$$\sigma^2 = \frac{\Omega}{2(1+K)} \tag{6}$$

where Ω= E[G^2]. This way we obtain both parameters v and σ.

We can finally substitute in the MIMO channel matrix in Eq. 1:

$$CH = \begin{bmatrix} CH_{1,1} \sim Rice(v_{1,1}\sigma_{1,1}^2) & \cdots & CH_{1,r} \sim Rice(v_{1,r}\sigma_{1,r}^2) \\ \vdots & \ddots & \vdots \\ CH_{t,1} \sim Rice(v_{t,1}\sigma_{t,1}^2) & \cdots & CH_{t,r} \sim Rice(v_{t,r}\sigma_{t,r}^2) \end{bmatrix} \tag{7}$$

The Eq. 7 can be further simplified by using v and σ parameters calculated using the rays between the transmitter and the center of the receiver array.

RESULTS

The downlink and uplink MIMO channel is simulated and measured in an indoor campus environment. The site is in the Communications Equipment and Technologies Department at the Technical university of Gabrovo. Fig. 4 shows a map of the building floor and the positions for downlink and uplink scenario.

It is used small cell wireless network deployment scenarios. The transmitter is equipped with the two-panel patch antenna (Ubiquiti NanoStation NSM 2 [8] in a 2x2 MIMO configuration and maximum gain level of 11.2 dBi combined with a properly configured MkroTik hAP RB962UiGS device [9]). The frequency of the channel measurement is 2,4 GHz. The transmitter power is set to be 100mW.

The simulation and measurement in the downlink and uplink scenarios was carried out with the transmitter at a fixed location TX and the receiver located in several different locations – from RX 1 to RX 9 (Fig. 4).

The channel simulation is based on the ray-tracing models developed in the Matlab environment. The work of [6] gave an example of channel modelling in indoor environment. The models includes the information about the structures and materials of the environment, which is imported through the building floor map (walls, doors, windows etc.).

The received signal power P is one of the most important parameters because it is strictly connected with the performance of the wireless network. The received power at a given location can be calculated as

$$P(x,y,z) = \left| \sum_{\alpha=1}^{q} G_\alpha(x,y,z) e^{-j\omega_0 \tau_\alpha(x,y,z)} \right|^2 \tag{8}$$

Using the simulated channel $H'_{m,n}$ and the measured channel $H_{m,n}$, the RMS (root mean square) error of simulation models is calculated:

$$RMS_{Error\ i,j} = \frac{1}{rt} \sum_{m,n=1}^{m=r,n=t} \sqrt{H_{m,n}^2 - H'(i,j)_{m,n}^2} \tag{9}$$

The obtained simulation and measurement results are summarized in Table 1m Table 2 and Fig. 5.

Figure 5a shows the comparison between the average received power of the measurements and the simulation results in the downlink scenario. Figure 5b shows the same comparison result in the uplink scenario. We can see that both results show good agreements.

The result in Table 1 and Table 2 shows that the RMS error for both simulation models is relatively small. This means that the overall accuracy of these models for MIMO systems with a small number of channels is relatively sufficient for the network planning and optimization purposes.

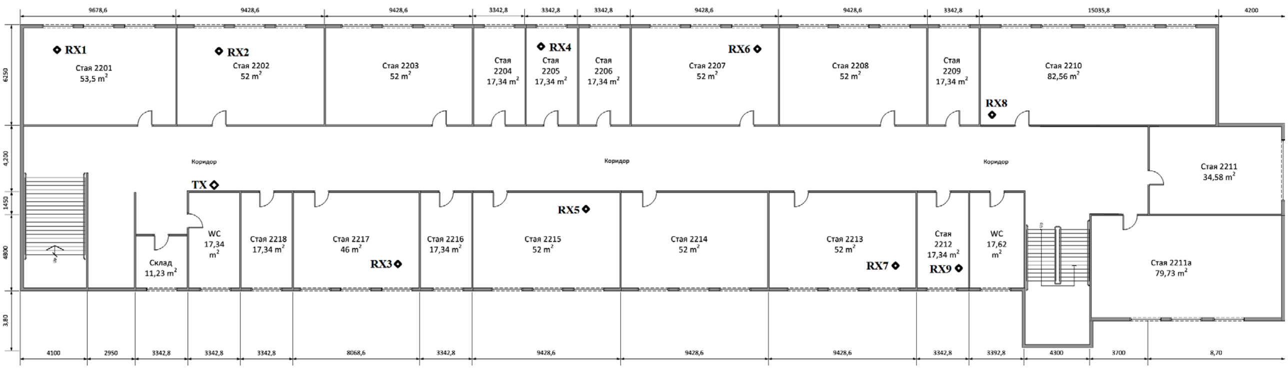


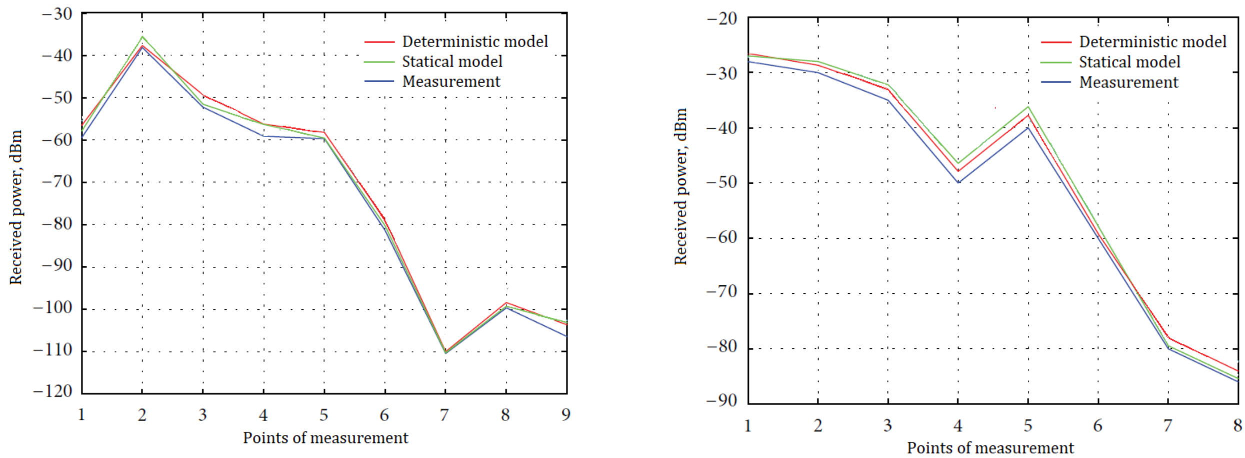
Fig. 4. *Building floor map for measurement campus-scenarios with TX and RX locations*

Table 1*. Received signal power and RMS error in downlink channel*

	Location:	1	2	3	4	5	6	7	8	9
Received signal power, dBm	Deterministic model	-56	-37,5	-49,5	-56,5	-57,5	-78,5	-109,5	-98	-102,5
	Statistical model	-58	-35	-51,5	-56,5	-59,5	-80	-110	-99	-103
	Measurement	-59	-38	-52,5	-58,5	-59,5	-81,5	-110,5	-99,5	-106,5
RMS error, dB	Deterministic model	2,68	2,17	2,52	2,68	2,70	3,16	3,71	3,51	3,61
	Statistical model	2,70	2,14	2,55	2,68	2,73	3,18	3,71	3,52	3,62

Table 2*. Received signal power and RMS error in uplink channel*

	Location:	1	2	3	4	5	6	7	8
Received signal power, dBm	Deterministic model	-26	-28	-33,5	-47,5	-37,5	-58,5	-77,5	-84
	Statistical model	-26,5	-27	-32,5	-45,5	-35,5	-57,5	-79	-86
	Measurement	-28	-30	-35	-50	-40	-60	-80	-86,5
RMS error, dB	Deterministic model	1,84	1,90	2,07	2,47	2,20	2,72	3,14	3,26
	Statistical model	1,85	1,89	2,05	2,44	2,17	2,71	3,15	3,28



a) b)

Fig. 5. *Average received power in a) downlink and b) uplink*

CONCLUSION

In this work, is proposed and analyzed two ray-tracing based simulation models for modelling of MIMO channel. The primary application of these models is network planning and optimization. We compare the simulation models with the measurement in a real small cell wireless network deployment environment (campus indoor environment). The comparison results show that the models have good agreements with the measurement. These ray-tracing based simulation models are efficient and accurate models, for planning and optimizing indoor networks equipped with MIMO access points.

ACKNOWLEDGMENT

The present work is supported under the "Creating innovative information-based educational training modules on communication equipment and technologies" 1712E project by the University Centre for Research and Technology at the Technical University of Gabrovo.

REFERENCES

[1] A. Abdi, C. Tepedelenlioglu, M. Kaveh, and G. Giannakis, On the estimation of the K parameter for the rice fading distribution, IEEE Communications Letters, vol. 5, no. 3,pp. 92–94, 2001.

[2] E. G. Larsson, F. Tufvesson, O. Edfors, and T. L. Marzetta, "Massive MIMO for next generation wireless systems," IEEE Communications Magazine, vol. 52, no. 2, pp. 186–195, 2014.

[3] E. Vitucci, V. Degli-Esposti, and F. Fuschini, MIMO channel characterization through ray tracing simulation, Proc. of the 1st European Conference on Antennas and Propagation (EuCAP '06), pp. 1–6, November 2006.

[4] K. Koychev, S. Sadinov and K. Angelov. Razpredelenie na trafika pri analiz na modeli v kletachna mrezha. UNITECH 2010, Proceedings, Vol. 1, стр.324-328, ISSN 1313-230X, Gabrovo, Bulgaria, 2010.

[5] M. Malamatoudis, P. Kogias, N. Manchev and S. Sadinov, Design, Implementation and Analysis of a Wireless Network Coverage Using a Nanostation, International Scientific Conference - UNITECH 2017, Gabrovo, ISSN 1313-230X, Vol. 2, pp. II-99-103, 2017.

[6] N. Tashkov, R. Tsvetkov, Research of radio frequency models in indoor scenario. Proc. of University of Ruse, Vol 55, book 3.2, ISSN 1311-3321, pp.19-24, 2016 г.

[7] Z. Lai, G. Roche, P. Kuonen, N. Bessis,, G. Clapworthy and J. Zhang, Intelligent Ray Launching Algorithm for Indoor Scenarios, Radioengineering, Vol. 20, No.2, pp. 398–408, June 2011.

[8] https://www.ubnt.com/airmax/nanostationm/

[9] https://mikrotik.com/products