Propagation modeling for evaluation of 4G systems

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Abstract

This paper discusses the channel modeling requirements and proposes a model for evaluation and dimensioning of the 4G systems. Existing 3G channel models are not suitable for 4G due to increased needs for flexible and efficient spectrum use. Recently 4G channel modeling has gained a lot of interest. One reason is the ongoing ITU-R IMT-Advanced process. We propose a geometry-based stochastic approach and introduce a generic model with a set of scenario specific parameters. The model was created in a European IST-WINNER project. It is claimed that this model with appropriate parameters applies for the upcoming 4G evaluations.

1. Introduction

The future wideband radio access technologies will utilise different multi-antenna techniques adaptively. The most advanced MIMO (Multiple Input, Multiple Output) schemes are designed to take advantage of rich multipath scattering in a way that improves the spectral efficiency significantly. However, the practical limitations related to the radio channel characteristics and the antennas set bound to the achievable performance gains. The actual propagation environment has also a large impact to the deployment of wideband radio access systems. Traditionally scenarios such as rural, suburban, urban, and indoors are modeled for performance evaluation purposes. In addition, the actual deployment scenarios cover numerous special cases ranging from outdoor-to-indoor and feeder links to high-speed trains. In order to have comparable simulation results it is important to agree on the reference radio channel models which are employed in the evaluation of different radio access technologies. The applied channel models have to reflect the instantaneous space-time-frequency characteristics that affect the adaptive exploitation of the radio channel in different MIMO modes (transmit/receive diversity, beamforming, and spatial multiplexing). In particular it is essential to model the phase angle relations and correlation between the signals of different antenna branches realistically which enables e.g. the fair comparison between the MIMO modes. The channel models shall support also the system level performance evaluation so that realistic multicell multiuser simulation is supported

MIMO channel modeling activities have been extensively carried out in European research projects and actions like COST259 [6], COST 273 [7] and IST-WINNER [10][12]. Corresponding research activities have been going on also in other continents [8]. Some of the most widely accepted models like IEEE 802.11n TGn models [13] and 3GPP/3GPP2 SCM [11] have been developed on standardization forums. The models are strongly related to channel characterisation of above mentioned research projects. Currently the ITU-R WG5D defines a channel model for IMT-Advanced that is the ITU-R concept for 4G model. The authors participated in the European B3G IST-WINNER project, where a geometry-based stochastic channel model approach was selected and channel models for more than 10 different propagation scenarios generated [1].

2. Requirements for 4G channel models

In the following we list the requirements for propagation models that are relevant for evaluation of 4G systems. We require that the model shall cover all the relevant propagation environments. More specifically, we emphasize that the following propagation scenarios should be covered: Urban macro-cell, urban micro-cell, suburban, rural, indoor, and outdoor-to-indoor. For most scenarios Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) models are needed. Furthermore, the model parameters for the different scenarios must be based on measurements. We also state the requirement that all the scenarios shall be modeled with a single generic modeling approach to keep the model implementation as simple as possible. 4G radio interfaces will operate in a wide frequency range and have a scalable bandwidth. Therefore the channel model shall cover the whole frequency range, from 450 MHz up to 6 GHz, and cover channel bandwidths up to 100 MHz with realistic frequency correlation.

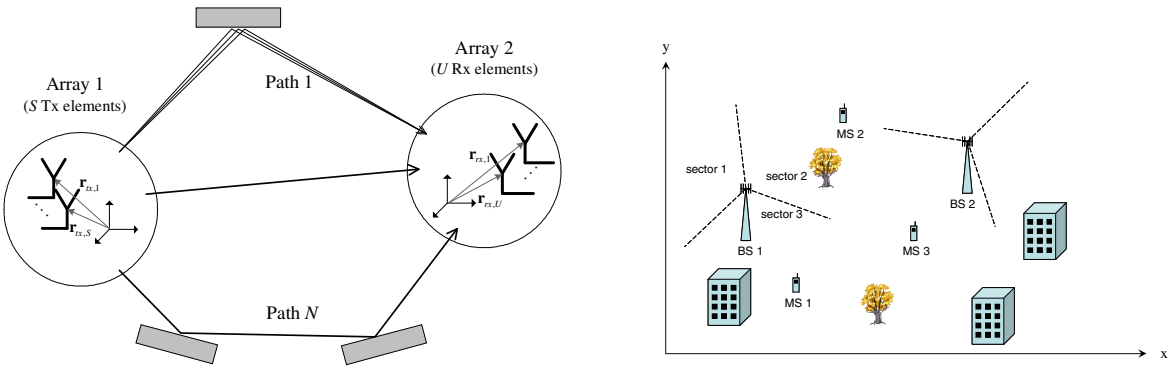
Channel model is by definition only an image of the reality and always a trade-off between realism and complexity. A multi-dimensional channel model should be dispersed in Doppler, delay, direction (at both transmitter (Tx) and receiver (Rx) ends) and polarization. Large scale effects like path loss, shadowing, number of propagation paths and dependencies between the large scale effects, should be modeled in a realistic way. A general purpose model has a generic structure, i.e. the mathematical framework to generate channel realizations is applicable for a various set of environments, represented by propagation parameters [9]. It is also favorable to differentiate the

propagation and antenna array effects [15]. When the two components are separable in the model, it is possible to investigate the propagation with different antenna configurations.

It is widely understood that the performance of a single link is not an adequate metric for the performance of any future system candidate. Therefore multilink channel modeling with realistic dependencies of various parameters is essential. Also in 4G systems the received power levels of the desired signal as well as the interfering signals have the strongest effect on link performance and system throughput. For this reason the path loss and shadow fading are the most important effects to model precisely in multi-link model. To be realistic, the model shall reproduce channels with accurate fast and slow fading characteristics. Statistical distributions of the parameters and the parameter behavior have to be similar to those found in radio channel from real channels by measurements. The model should represent typical behavior of the channel, so that the simulation results would show realistic results. On the other hand, the model should be able to produce realistic extreme conditions, e.g. extremely large delay spread.

3. MIMO channel models

One way of modeling MIMO links is the geometry-based stochastic approach. The simplified link is shown in the figure 1 a below.



a b

Figure 1. a) MIMO link. b) Multi-link lay-out.

The channel is composed of N paths. In general, N is variable. Each path has a delay, angle of departure and angle of arrival as seen in the Figure 1 a. In addition, each path has its gain and cross-polarization power ratio (XPR). There are three types of paths: Direct (LoS) paths, single-bounce paths and multi-bounce paths (see figure 1 a). Each path n consists of M_n sub-paths called rays, like shown for path 1 in the figure, except direct path that consists of one single path. Due to this distributed nature of the paths, they are also called clusters. The rays are assumed to have random phases and the Doppler spread is caused by the movement of the transmitter, receiver or scatterers. The channel from Tx antenna element s to Rx element u for cluster n is described by (1).

$$\begin{aligned}\mathrm{H}_{u,s,n}(t;\tau) = \sum_{m=1}^{M} & \begin{bmatrix} F_{rx,u,V}(\varphi_{n,m}) \\ F_{rx,u,H}(\varphi_{n,m}) \end{bmatrix}^T \begin{bmatrix} \alpha_{n,m,VV} & \alpha_{n,m,VH} \\ \alpha_{n,m,HV} & a_{n,m,HH} \end{bmatrix} \begin{bmatrix} F_{tx,s,V}(\phi_{n,m}) \\ F_{tx,s,H}(\phi_{n,m}) \end{bmatrix} \\ & \times \exp\left(j2\pi\lambda_0^{-1}\left(\overline{\varphi}_{n,m}\cdot\overline{r}_{rx,u}\right)\right)\exp\left(j2\pi\lambda_0^{-1}\left(\overline{\phi}_{n,m}\cdot\overline{r}_{tx,s}\right)\right) \\ & \times \exp\left(j2\pi\upsilon_{n,m}t\right)\delta\left(\tau-\tau_{n,m}\right)\end{aligned} \tag{1}$$

In (1) M is the number of rays in the cluster, $F_{rx,u,V}$ and $F_{rx,u,H}$ are the antenna element u field patterns for vertical and horizontal polarisations respectively, $\alpha_{n,m,VV}$ and $\alpha_{n,m,VH}$ are the complex gains of vertical-to-vertical and horizontal-to-vertical polarisations of ray n,m respectively. Further λ_0 is the wave length of carrier frequency, $\overline{\phi}_{n,m}$ is AoD unit vector, $\overline{\varphi}_{n,m}$ is AoA unit vector, $\overline{r}_{tx,s}$ and $\overline{r}_{rx,u}$ are the location vectors of element s and u respectively, and $\upsilon_{n,m}$ is the Doppler frequency component of ray n,m. If the radio channel is modeled as dynamic, all the above mentioned small scale parameters are time variant, i.e. function of t.

The normalized power-weighed distribution of path delays is called Power Delay Profile (PDP). Corresponding distributions of path angles are Power Azimuth Spread (PAS) at Tx and Rx. (For simplicity, we assume the angles

defined in horizontal plane.) Square root of second moment of the PDP is the RMS delay spread. Corresponding measure for the PAS is the RMS azimuth spread, specified for Tx and Rx. These parameters are proper measures of the extent of PDP and PASs. Instantaneous path gains average (in dB) to the PDP, but they have a random component on top of them described by the per-cluster shadowing. It is well-known that the RMS delay spread is a random variable as function of terminal position. Similarly the RMS azimuth spreads at Tx and Rx are random variables. The power-weighed distribution of the ray directions and delays within a path is described by intra-cluster azimuth spreads at Tx and Rx and intra-cluster delay spread. This intra-cluster angle spread causes the fading of each path. The number of rays in a path is variable in real channels. The small-scale fading of each path is caused by superposition of several rays approaching from different angles of arrival.

By adding cross-polarization ratio (XPR) to the parameters discussed so far we get a framework for the geometry-based generic channel model. At this point we need to fix the statistical distributions and parameters to obtain an unambiguous model. This is done in section 4. Here it is sufficient to note that, excluding path-loss and shadowing, the channel model can be specified with the following parameters: PDP, PAS at Tx and Rx, XPR, number of clusters, number of rays in a cluster, intra-cluster PDP, PAS at Tx and Rx and intra-cluster shadowing.

4. WINNER Channel Model for 4G evaluations

WINNER Channel Model is geometry-based stochastic model [1]. Model parameters are based on the measurements performed in the IST-WINNER project [5] [13] [1] and partly also on results found in literature. Model approach is quite near the similar with 3GPP SCM [4][15], COST 259 [6] and COST273 models [7]. In several publications. e.g. [3], it has been shown that the PDP of a channel can be modeled by one or more exponential functions in NLoS conditions. We decided to use one exponential function for simplicity. In LoS conditions, at least one strong path representing the direct path has to be added. It has also been shown that the intra-cluster azimuth spread is Laplacian [2]. The over-all azimuth distribution has been modeled by Laplacian distribution or by von Mises distribution. However, we decided to model the PAS with wrapped Gaussian distribution, i.e. Gaussian distribution with tails wrapped over $\pm 180^{o}$. In [2] it has been shown that RMS delay spread and corresponding azimuth spreads have log-normal distribution. It is also well-known that shadow fading has log-normal distribution, as well as the Ricean K-factor of the LoS channel.

We selected the distributions for our model as described above. We fixed the number of intra-cluster rays to 20. We also fixed the number of clusters to different values for different scenarios, ranging from 8 to 24. Parameters of WINNER channel model are given in the following table. In addition, a stepwise procedure for generating the channel coefficients is needed, which is given in [1]. Cross-correlations between the LS parameters, as well as correlation distances of them are left out for brevity. The full list of parameters can be found in [1].

Table 1. Channel model parameters.

Scenarios		Indoor		Urban micro-cell		Outdoor-to-indoor	Urban macro-cell		Rural	
		LOS	NLOS	LOS	NLOS	NLOS	LOS	NLOS	LOS	NLOS
Delay spread (*DS*) $\log_{10}([s])$	μ	-7.42	-7.60	-7.44	-7.12	-7.39	-7.39	-6.63	-7.80	-7.60
	σ	0.27	0.19	0.25	0.12	0.36	0.63	0.32	0.57	0.48
AoD spread (*ASD*) $\log_{10}([°])$	μ	1.64	1.73	0.40	1.19	1.25	1	0.93	0.78	0.96
	σ	0.31	0.23	0.37	0.21	0.42	0.25	0.22	0.21	0.45
AoA spread (*ASA*) $\log_{10}([°])$	μ	1.65	1.69	1.40	1.55	1.76	1.7	1.72	1.20	1.52
	σ	0.26	0.14	0.20	0.20	0.16	0.19	0.14	0.18	0.27
Shadow fading (*SF*) [dB]	σ	3	4	3	4	7	4/6 +	8	4/6 +	8
K-factor (*K*) [dB]	μ	7	N/A	9	N/A	N/A	7	N/A	7	N/A
	σ	6	N/A	6	N/A	N/A	3	N/A	6	N/A
Delay distribution		Exp	Exp	Exp	Uniform	Exp	Exp	Exp	Exp	Exp
AoA and AoD distribution		Wrapped Gaussian								
XPR [dB]	μ	11	10	9	8.0	9	8	7	12	7
	σ	4	4	3	3	11	4	3	8	4
Number of clusters		12	16	8	16	12	8	20	11	10
Number of rays per cluster		20	20	20	20	20	20	20	20	20
Cluster *ASD*		5	5	3	10	5	6	2	2	2
Cluster *ASA*		5	5	18	22	8	12	15	3	3
Per cluster shadowing std ζ [dB]		6	3	3	3	4	3	3	3	3

The path loss models are typically of the form of (2), where d is the distance between the transmitter and the receiver in [m], f_c is the carrier frequency in [GHz], the fitting parameter A includes the path-loss exponent, B is the intercept, C describes the path loss frequency dependence, and X is an optional, environment-specific term.

$$PL = A\log_{10}(d[\mathrm{m}]) + B + C\log_{10}\left(\frac{f_c[\mathrm{GHz}]}{5.0}\right) + X \tag{2}$$

The applied method of time evolution is based on snap-shots (or sc. drops). Simulation goes in a snapshot by snapshot manner, with all parameters fixed during a snapshot except the random phases of the rays to generate the fast fading phenomenon, until the simulation results are stable enough. Next drop is started with new random parameters and so on. The process is repeated over so many drops that the global results are satisfactory.

The model is currently defined in the frequency range 2 – 6 GHz. In section 2 it was stated that the channel model has to cover also frequencies from 450 to 2000 MHz. The generic model introduced can be readily generalized to this (or any) frequency range. What is needed is to find out the parameter values for the desired scenarios. This is a work that needs to be performed in a near future.

5. Conclusion

A channel model for the assessment of 4G systems should be a balanced combination of reasonable complexity and all the above mentioned characteristics. For the complexity reasons it is beneficial to have a single generic model concept for all the propagation environments. Because different type of simulations may require varying level of accuracy of the channel model, it is recommended to have a single and accurate model which can be approximated to different purposes.

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7. References

[1] WINNER II WP1: “WINNER II Channel Models, Part I Channel Models”. Deliverable D1.1.2, v 1.2, 4.2. 2008.

[2] A. Algans, K. I. Pedersen, P.E. Mogensen,”Experimental analysis of the joint statistical properties of azimuth spread, delay spread and shadow fading”, IEEE J. Selected Areas in Comm., Vol. 20, pp.523-531, 2002.

[3] A. A. M. Saleh, R. A. Valenzuela, "A Statistical Model for Indoor Multipath Propagation", IEEE Journal on Selected Areas in Communications, Vol. SAC-5, No. 2, February 1987, pp. 128-137.

[4] 3GPP TR 25.996: Spatial Channel Model for Multiple Input Multiple Output (MIMO) simulations, V6.1.0 (2003-09).

[5] WINNER1 WP5: “Final Report on Link Level and System Level Channel Models” Deliverable D5.4, 18.11.2005

[6] L. M. Correia, Ed., Wireless Flexible Personalised Communications (COST 259 Final Report). Chichester (UK): Wiley, 2001.

[7] L. Correia, Ed., Mobile Broadband Multimedia Networks (COST 273 Final Report). Wiley, 2006.

[8] Rahim Tafazolli (Editor). Technologies for the Wireless Future: Wireless World Research Forum (WWRF), Volume 2. April 2006,

[9] A. F. Molisch, “A Generic Model for the MIMO Wireless Propagation Channels in Macro- and Microcells,” IEEE Trans. on Signal Proc., vol. 52, no. 1, pp. 61–71, Jan. 2004

[10] H. El-Sallabi, D.S. Baum, P. Zetterberg, P. Kyösti, T. Rautiainen, C. Schneider, "Wideband Spatial Channel Model for MIMO Systems at 5 GHz in Indoor and Outdoor Environments" in Proc. IEEE Veh. Technol. Conf. VTC'06 Spring, Melbourne, Australia, vol. 6, pp. 2916-2921, May 2006.

[11] 3GPP TR 25.996, "3rd Generation Partnership Project; technical specification group radio access networks; spatial channel model for MIMO simulations (release 6)", V6.1.0.

[12] WINNER1 WP5: "Final Report on Link Level and System Level Channel Models" Deliverable D5.4, 2005.

[13] V. Erceg et al. “TGn Channel Models,” IEEE P802.11 Wireless LANs, Tech. Rep., May 2004, http://www.802wirelessworld.com:8802/

[14] WINNER2 WP1: "WINNER2 interim channel models" Deliverable D1.1.1, 2006.

[15] G. Calcev, D. Chizhik, B. Goeransson, S. Howard, H. Huang, A. Kogiantis, A. F. Molisch, A. L. Moustakas, D. Reed and H. Xu, “A Wideband Spatial Channel Model for System-Wide Simulations”, IEEE Trans. Veh. Tech.

[16] M. Steinbauer, A. F. Molisch, and E. Bonek, "The double-directional radio channel," IEEE Antennas and Propagation Mag., pp. 51-63, August 2001.