Modeling and Simulation of Fast Fading Channels in Indoor Peer-to-Peer Scenarios

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I. Introduction

Traditional cellular solutions are coming under increasing pressure from wireless peer-to-peer (P2P) systems. The growing interest in wireless indoor communication systems has resulted in many investigations on the characteristics of indoor radio propagation channels. In [1], various properties of indoor peer-to-peer channels have been analyzed for static nodes only. In [2], peer-to-peer channels were investigated in a typical US office environment, consisting in a large indoor area containing individual cubicle-style offices. The same environment was also used in [3] to investigate the multi-user separation in dual-link MIMO indoor scenarios.

In this paper, we investigate narrowband indoor distributed channels based on an experimental campaign in an office environment. We evaluate the fast fading statistics using the second-order scattering fading (SOSF) distribution [4], [2]. It turns out from the measurements that the fading statistics change over time. An approach to model these effects is proposed.

II. Measurements

Our results are based on indoor peer-to-peer measurements in an office environment consisting in different rooms aligned along a corridor and separated by different types of walls. Mobile nodes were either randomly moved over a small scale (within a square of 1 m^2), or over a larger scale (throughout the whole room they were in). The measurements were carried out with UCL/ULB Elektrobit CS channel sounder at a carrier frequency of 3.8 GHz [5].

Following the concept of [2], the channel can be seen as a superposition of path loss, static shadowing, dynamic shadowing, and fast fading. The path loss and shadowing were removed to obtain only fast fading component of the channels.

Our goal is to create a model which generates fast fading realizations taking into account both first- and second-order statistics. However, measurement parameters do not permit us to extract appropriate second-order statistics from samples. For this reason, we need to derive second order statistics analytically,using an equivalent reference model.

III. Time-variant fast fading statistics

It is shown in [2] that for peer-to-peer environments fast-fading amplitude can be described by a single distribution including a weighted combination a line-of-sight (LOS) component, a Rayleigh fading component and a Double Rayleigh fading component. Hence, any realization of the channel can be expressed as

$$g = \omega_0 e^{j\theta} + \omega_1 G_1 + \omega_2 G_2 G_3 \quad (1)$$

where G_1, G_2, G_3 are i.i.d. complex normal random variables with zero mean and unit variance, and θ is a constant phase shift angle in [0, 2π]. The probability density function of $r = |g|$ is given as shown in [6] and [2] by the so-called second order scattering fading (SOSF) distribution. The distribution can be specified by two parameters $\alpha = \frac{\omega_2^2}{\omega_0^2+\omega_1^2+\omega_2^2}$ and $\beta = \frac{\omega_0^2}{\omega_0^2+\omega_1^2+\omega_2^2}$ [7]. Values of the parameters can be partitioned into five groups: (i) Rician ($\alpha = 0, \beta > 0$, with K-Factor $K = \frac{\beta}{1-\beta}$), (ii) Rayleigh ($\alpha = 0, \beta = 0$), (iii) Double Rayleigh (DR) ($\alpha = 1, \beta = 0$), (iv) Double Rayleigh under LOS conditions (DRLOS) ($\alpha + \beta = 1, \alpha < 1, \beta < 1$), (v) Rayleigh-Double-Rayleigh (RDR) subset ($0 < \alpha < 1, \beta = 0$).

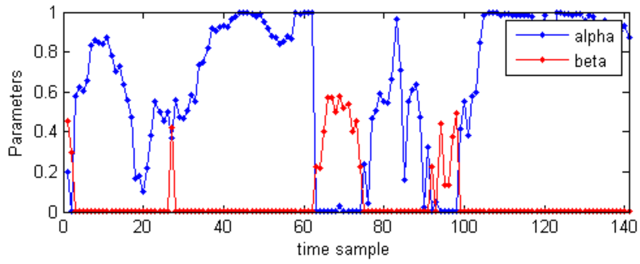

Fig. 1. Example of fast-fading distribution parameters over time for double mobile small-scale motion.

It turns out from measurements that the parameters α and β for peer-to-peer channels depend on time. Looking at the variability of the parameters for an exemplary double-mobile channel (with small-scale motion) in Fig. 1, we see that predominantly Rayleigh-Double-Rayleigh fading occurs. Only scarcely, we observe other kinds of fading. For single-mobile channels, we observe Rayleigh fading and Rician fading. It turns out that the distribution of the parameter α for the RDR subset can be well approximated by the Beta distribution. For the DRLOS subset, we define $\Delta = \sqrt{(1-\alpha)^2 + \beta^2}$. It turns out that Δ is Beta-distributed. Finally, the distribution of the K-Factor $K = \frac{\beta}{1-\beta}$ can be modeled by Extremal Value Distribution. By that, we can estimate a probability distribution of the SOSF parameters within the subset. A summary of these parameters evaluated from the measurements is provided in Table I.

TABLE I
EVALUATED PARAMETERS OF THE SOSF DISTRIBUTION FOR DIFFERENT MOBILITY

Subset	Small scale motion Distribution	Large scale motion Distribution
Single mobile		
Rician	$K \sim p_{ev}(-0.8, 3), \alpha = 0$	$K \sim p_{ev}(-0.44, 2.8), \alpha = 0$
Double mobile		
Rician	$K \sim p_{ev}(-1.4, 3.5), \alpha = 0$	$K \sim p_{ev}(-2.4, 2.6), \alpha = 0$
RDR	$\alpha \sim p_{\beta}(2, 0.85), \beta = 0$	$\alpha \sim p_{\beta}(2.4, 0.7), \beta = 0$
DRLOS	$\Delta \sim p_{\beta}(1, 0.85)$	$\Delta \sim p_{\beta}(1.9, 3.5)$

TABLE II
TRANSITION MATRICES FOR SINGLE MOBILE SUBSCENARIOS

	Probability		Transition matrix	
Subset	Small Scale	Large Scale	Rician	Rayleigh
Rician	0.25	0.16	0.77	0.23
Rayleigh	0.75	0.84	0.06	0.94

Modeling transitions between different fading distributions can be solved by using a hidden Markov model (HMM) [8]. As an example, the state transition probabilities for single mobile scenarios, estimated from the measurements, are presented in Table II.

Using the Double Ring geometry (Fig. 2) described in [9], we are able to derive a reference model for SOSF. Next, using the model, the autocorrelation function of SOSF can be expressed as

$$\begin{aligned} R_{gg}(\tau) =& \mathbb{E}[g(t)g^*(t+\tau)] = \\ & (\omega_1^2 + \omega_2^2) J_0(2\pi f_T \tau) J_0(2\pi f_R \tau) \\ & + \omega_0^2 \cos(2\pi f_{rel} \cos(\Theta_{rel})) \end{aligned} \quad (2)$$

where f_T, f_R, f_{rel} and Θ_{rel} are the maximum Doppler frequencies caused by the movement of the transmitter/the receiver, the relative movement of the nodes and the angle between the relative movement and the LOS component, respectively. By that, we can simulate fast fading reproducing both first- and second-order statistics.

IV. MODEL SUMMARY

Summarizing, we propose to model small-scale fading with time-variant statistics using following procedure: We start with a random initial state of the HMM. Depending on the state, we set constant values of the SOSF parameters (α, β) or check if the state is changed in comparison with the previous one (skipped for the initial state). If the state is unchanged we use an autoregressive model to generate new values of α, β or Δ. Otherwise, we draw new values of the parameters using distributions described in Table I. Using (α, β), we generate a pre-defined number of complex fading realizations $g(t)$ using the first- and second-order statistics previously derived. Next, the state of the HMM is updated.

V. CONCLUSIONS

This paper has presented an analysis and an empirical model of time-variant fading statistics of a peer-to-peer network

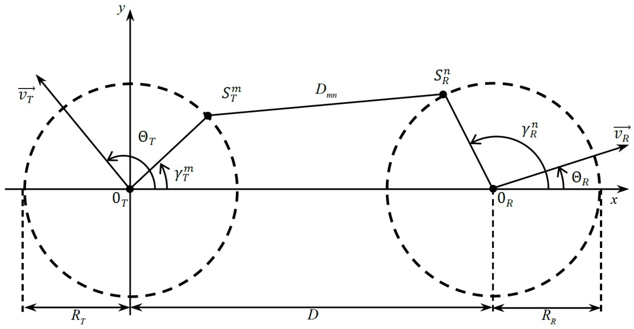

Fig. 2. The geometrical double-ring model with local scatterers around a mobile transmitter(left) and a mobile receiver(right)

based on measurement in an indoor office environment at 3.8 GHz: (i) Models and simulators for second-order scattering fading (SOSF) in different mobility scenarios have been proposed; (ii) In double mobile scenarios, the measured data is characterized by the SOSF distribution; (iii) In single mobile scenarios, fast-fading is Rayleigh or Rician distributed; (iv) Distributions of the parameter α for the RDR and Δ for the DRLOS subsets can be well approximated by the Beta distribution; (v) Distribution of the K-Factor can be modeled by the Extremal Value Distribution; (vi) Transitions between the groups are described by a hidden Markov model.

VI. ACKNOWLEDGEMENTS

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