An Autocorrelation Model for Shadow Fading in Urban Macro Environments

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Abstract

We propose an autocorrelation model of the SF (shadow fading) in urban macro environments. The proposed model is based on the empirical autocorrelations obtained from the wideband channel measurements at 2.38 GHz. The proposed model outperforms an existing model in terms of the match to empirical autocorrelations in individual measurement routes.

Keywords : Autocorrelation Measurement Shadow Fading

1. Introduction

The performance of mobile radio systems is highly dependent on the fading phenomena, FF (fast fading) and SF (shadow fading). The FF results from the superposition of randomly scattered multipath replicas. The statistical properties of FF have been investigated extensively in the literature [1]. The SF occurs mainly due to the effects of buildings and terrain features and determines variations of the local mean. Experimental results have shown that the SF can be modeled as a RV (random variable) whose logarithm is normally distributed [2], [3].

The autocorrelation behavior of the SF is important in the mobile communication technologies such as the design of handover scheme [4] and the coverage of multihop cellular systems [5]. Based on the measurement data in urban micro and suburban macro environments, a simple exponential model has been proposed in [6] for the ACF (autocorrelation function). The modification of this model to be compatible with the level crossing theory has been proposed in [7]. Recently, based on the measured data in urban macro environments, which are a mixture of LOS (line-of-sight) and NLOS (non line-of-sight) conditions but mostly NLOS, the EDS (exponential decaying sinusoid) model has been proposed in [2] for empirical ACFs of individual routes.

In this paper, based on the measured data at 2.38 GHz, we propose an autocorrelation model of SF for LOS and NLOS urban macro environments. We show that the proposed model provides a better match to empirical ACFs of individual routes than the EDS model.

2. Measurement Campaign

The measurements were performed at the center frequency of 2.38 GHz with the BECS (band exploration and channel sounding) 2006 Plus system in Gwangju and Busna, Korea. The BECS 2006 Plus utilizes the TDM (time division multiplexing) based transmission (or reception) of PN (pseudo noise) sequences. The sounding procedure can refer to that of BECS 2005 system found in [8]. The BECS 2006 Plus specification used in the measurements is summarized in Table 1. The Tx (transmitting) and Rx (receiving) systems use a ULA (uniform linear array) consisting of four antennas, which are collinear dipoles and quarter wave monopoles, respectively. Tx and Rx antenna spacings are fixed to 10λ and 0.5λ, respectively, where λ denotes the wavelength. Table 2 shows the measurement scenarios. Fig. 1 shows the LOS route (i.e., Scenario A) and NLOS routes (i.e., Scenario C and D). In Fig. 1, the Tx denotes the location of the Tx antenna array. The Rx antenna array was mounted on the roof of a measurement van approximately 2 m above the ground. From the starting point of each route, we drive along each route at a speed of around 10 km/h.

Table 1: BECS 2006 Plus Specification

Parameter	Frequency [GHz]	Bandwidth [MHz]	PN Length [chips]	Transmitted Power [dBm]
value	2.38	20	4096	37.2

Table 2: Measurement Scenarios

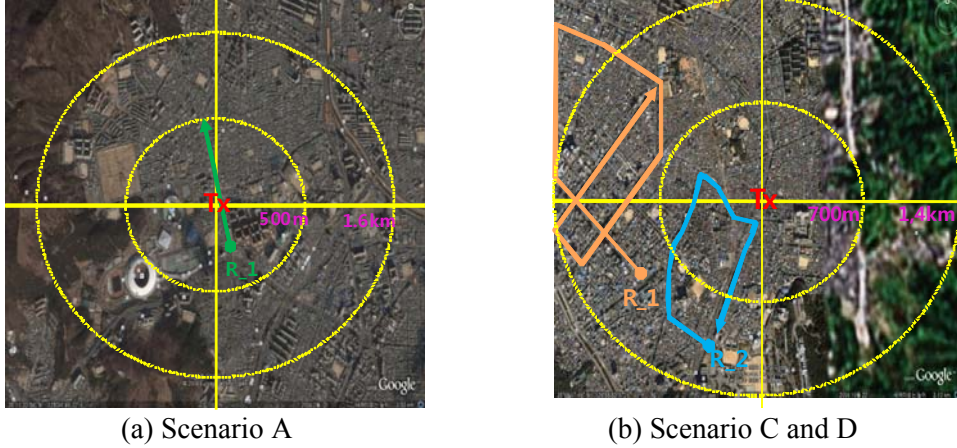| Scenario	LOS		NLOS			
	A	B	C	D	E	F
Route	R_1	R_2	R_1	R_2	R_3	R_4
Tx antenna height [m]	52	51	22	22	51	51

(a) Scenario A   (b) Scenario C and D

Figure 1: Measurement Environments. The location of Tx antenna array is marked with Tx.

3. Analysis of the Measurement Data

3.1 Extraction of the Shadow Fading Component

The total received power at a Tx-Rx separation of d in meters is given by

$$P_R(d) = P_D(d) + P_S(d) + P_F(d), \tag{1}$$

where $P_D(d)$ is the component of received signal strength, which is proportional to the PL (path loss) exponent n, and is given by

$$P_D(d) = P_{ref}(d_0) - 10n \log_{10}\left(\frac{d}{d_0}\right), \tag{2}$$

where $P_{ref}(d_0)$ is a reference received power level at distance d_0 from the Tx antennas, $P_S(d)$ is the SF component, $P_F(d)$ is the FF component, and all components are in decibels. The PL in decibels is defined as

$$PL(d) = P_T - P_R(d) + G_T + G_R, \tag{3}$$

where P_T, G_T and G_R are the transmitted power, Tx and Rx antenna gains, respectively. In the measurements, Tx and Rx antenna gains are 11 dBi and 0 dBi, respectively. The single slope log-distance model to estimate the distance dependent PL is expressed as [9]

$$PL_M(d) = 10n \log_{10}(d) + A + B \log_{10}(f_c), \tag{4}$$

where n is the PL exponent, f_c is the center frequency in GHz, A is the interception in decibel, and B describes the frequency dependent factor in decibel. Linear regression using a MMSE (minimum mean square error) criterion was utilized to estimate the n, A, and B in our measured data. The fitted

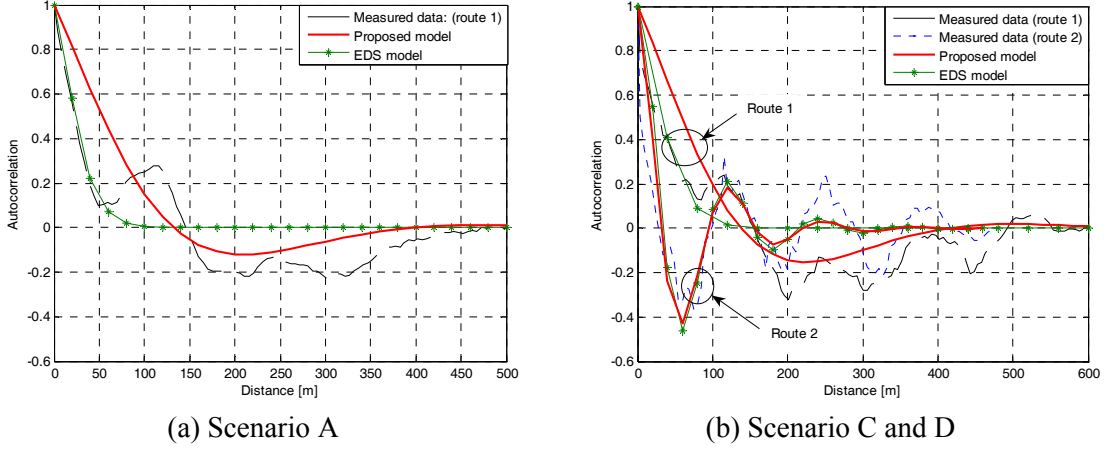(a) Scenario A   (b) Scenario C and D

Figure 2: Empirical ACFs of SF obtained in Scenario A , C, and D. The proposed and EDS models fitted to empirical results are also plotted.

Table 3: Fitted Parameters

Scenario		LOS		NLOS			
		A	B	C	D	E	F
Parameter [m]	d_A	112	94	132	72	201	93
	d_B	84	45	88	20	39	84
	d_C	14	98	20	77	214	21
	d_D	$>10^5$	38	$>10^5$	19	38	$>10^5$

parameters are $n = 2.41$, $A = 19.8$, and $B = 30$ for the LOS condition and $n = 3.31$, $A = 15.3$, and $B = 18.2$ for the NLOS condition, respectively. In order to estimate the SF component, the FF component in $P_R(d)$ needs to be properly removed. Let $P_R'(d)$ denote the averaged received power with proper window size [10]. It is assumed that the FF is removed, so the received power in decibels approximates the summation of $P_D(d)$ and $P_S(d)$. Thus, the SF component is given by

$$P_S(d) = PL_M(d) - \left(P_T - P_R'(d) + G_T + G_R\right). \qquad (5)$$

3.2 Autocorrelation Model for Shadow Fading

Let $\mathcal{C} = \{P_S'(1), P_S'(2), ..., P_S'(N)\}$ be the extracted SF samples where the distance resolution between samples is $\Delta d = 40\lambda$. The ACF of SF, denoted by $\rho(d_k)$, is then estimated over set $\mathcal{C}$ at a series of discrete distance d_k as

$$\rho(d_k) = \left| \frac{\sum_{i=1}^{N-k} P_S'(i) P_S'(i+k)}{\sum_{i=1}^{N} \{P_S'(i)\}^2} \right|, \qquad (6)$$

where $d_k = k\Delta d$ and $0 \le k \le N-1$. Fig. 2 shows the empirical ACFs of SF in Scenario A, C, and D. Based on visual inspections of empirical ACFs, we propose the autocorrelation model as an EDFF (exponentially decreasing fluctuation function),

$$\rho(d) = \exp\left(-\frac{|d|}{d_A}\right)\cos\left(\frac{|d|}{d_B}\right), \qquad (7)$$

where $d_A > 0$ and $d_B > 0$. Fig. 2 also shows the proposed model fitted to empirical ACFs from the measured data. As a reference, we also include the EDS model, which is represented by [2]

$$\rho(d) = \exp\left(-\frac{|d|}{d_C}\right)\left[\cos\left(\frac{|d|}{d_D}\right) + \frac{d_D}{d_C}\sin\left(\frac{|d|}{d_D}\right)\right], \qquad (8)$$

where $d_C > 0$ and $d_D > 0$. The fitted parameters (i.e., d_A, d_B, d_C, and d_D) are extracted by using LSE (least square error) method such that the difference between the measured data and the model is minimized. The fitted parameters are summarized in Table 3. It can be seen that although the EDS model does not fit the empirical ACFs well, the proposed model matches well with empirical ACFs. It shows that the d_D of the EDS model is greater than 10^5 m at three scenarios. However, it is noted that unlike the EDS model, the proposed model is not compatible with the level crossing theory [2].

4. Conclusion

This paper presented the ACFs of SF in the urban macro environments at 2.38 GHz. The EDFF as an autocorrelation model was proposed based on the empirical ACFs of the measured data. The proposed model gives better match to empirical ACFs of individual routes than the EDS model. The proposed model thus provides the ability to generate realistic ACFs of individual routes in urban macro environments at 2.38 GHz.

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