MEASUREMENT AND MODELLING OF SMALL-CELL SHADOWING CROSS-CORRELATION AT 2GHZ AND 5GHZ

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1. Introduction

This paper describes a novel method for generating synthetic correlated shadowing for wireless systems in the absence of detailed propagation and landscape information, based on the statistical properties of measured data in indoor environments. The study of shadowing correlation presented in the paper is an outcome of two measurement campaigns carried out within the Mobile Virtual Centre of Excellence project ([1]).

The angle of arrival difference between multiple transmitters at the receiver is the input parameter to a model which yields appropriate values for the correlation coefficients. The coefficients are then used as input to a synthetic shadowing generator.

The model has applications in the assessment of system simulation and design, where it is essential for generating realistic co-channel interference statistics, which in turn affects the overall capacity of a wireless system.

2. Correlated Shadowing

Existing models for simulating shadowing effects on wireless systems postulate a zero mean log-normal marginal distribution for the fading signal power. As reported in [2] the shadowing experienced on nearby paths is correlated due to the structure of the environment.

Fig. 1 shows the possible paths between two mobiles and two base stations. The shadowing on each path in decibels can be described by the zero-mean Gaussian random variables: S_{11}, S_{12}, S_{21} and S_{22}. Two types of correlation are taken into consideration: *shadowing auto-correlation* (ρ_s in (1)), which determines the dynamics of shadowing for a moving mobile and *shadowing cross-correlation* (ρ_c in (1)), which determines how the level of co-channel interference varies relative to a wanted signal.

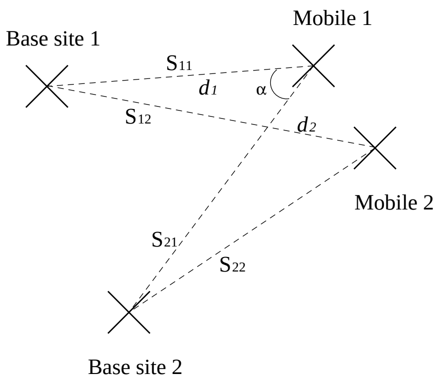

Fig. 1: Shadowing paths between two mobiles and two base stations ([2])

The two type of correlation are calculated as:

$$\rho_s = \frac{E[S_{11} \cdot S_{12}]}{\sigma_1 \cdot \sigma_2} \qquad \rho_c = \frac{E[S_{11} \cdot S_{21}]}{\sigma_1 \cdot \sigma_2} \qquad (1)$$

where σ_1 and σ_2 are the location variability (standard deviation) in dB corresponding to the two paths and *E[.]* denotes expectation.

Reference [3] proposed a shadowing autocorrelation function which follows an exponential decrease with distance and this approach has been adopted by several other authors. The effects of shadowing crosscorrelation, by contrast, have received relatively little attention: [4] described the effects of crosscorrelation for outdoor environments, whereas [5] showed the influence on system capacity for an indoor environment. The analysis of crosscorrelation of shadowing described in this paper is based initially on the method proposed for the outdoor environment in [2], where two variables are taken into consideration: the angle between the two paths from the base stations to the mobile (α in Fig. 1) ratio between the two path lengths (d_1/d_2).

2.1 Analysis of shadowing

One set of measurements analysed in this paper was carried out at the Centre for Communication Systems Research, at the University of Surrey (UK). The channel sounder employed included six simultaneously sampled narrowband receivers, and a transmitter mounted on a mobile platform. The details of the measurement campaign and data analysis are presented in reference [6].

Fig. 2a and Fig. 3a show the results of the analysis of the shadowing correlation against the angle between the paths to the six receivers, as the mobile platform moves around the Centre. In order to calculate the correlation coefficients the mobile path was divided into sections, with the length of each section taken to be equal to the *shadowing correlation distance* r_c, which was found from the measurements to be 15m for 2.4GHz and 7m for 5.2GHz. For each section, the angle between each pair of receivers for each sample was calculated. After ordering the samples in 18 bins, each spanning 10°, the correlation coefficient was calculated as ρ_c in (1).

As shown in [2], the correlation decreases as the angle increases, due to the fact that for small angles the path profiles share many common elements leading to a high correlation. However, unlike the outdoor case where the correlation tends to zero for large angles ([2]), the correlation for angles larger than 90° is found to have a negative trend. This suggests that the shadowing in one path increases as the other decreases, agreeing with the results presented in [5]. The spread of correlation values shown in the graphs is due mainly to the finite amount of data available for the estimation in each bin, but a reasonable empirical model for the shape of the correlation with respect to the angle between paths follows the shape of a cosine (dotted line in the graphs) for both 2.4 and 5.2GHz.

Analysis of shadowing with respect to the relative distance did not show any significant correlation, which may be due to the fact that too few samples were used in order to generate valid statistics plus the high variability in path loss, for paths of a given length due to the presence or absence of attenuating walls [7]. Therefore, the correlation of shadowing between any two receivers is given by:

$$\rho_{12} = \beta \cdot \cos(\alpha) \qquad (2)$$

where α is the angle difference between two shadowing paths, β is a constant factor which depends on the environment and the frequency.

Fig. 5 shows the correlation results found from an indoor to outdoor measurement campaign carried out in three locations in the UK (Bradford, Bristol and Surrey) employing a wideband channel sounder working at 2.45GHz, details of the campaign which was sponsored by the VCE are described in reference [8]. The analysis of the measurements shown in two of the locations (Bradford and Surrey) have correlation shapes which can be approximated by (2). The measurements in Bristol do not follow the proposed model, perhaps because of additional floor losses at this site introduced by differences in transmitter and receiver height due to the hilly terrain.

3. Simulation of correlated shadowing and results

In order to generate a spatially correlated shadow-fading pattern with desired statistics the following method is proposed:

- Generate a number of Gaussian processes with zero mean and unity standard deviation. Each random process represents the shadowing affecting each receiver and each sample represents a different position of the transmitter.
- The autocorrelation process is modelled by filtering each random sequence. The filter used is a first order IIR filter, its coefficient being dependent on the correlation distance r_c.
- Construct the covariance matrix, shown in (3), by assuming that the variance of the shadowing (σ_n) is the same for each path. This is a reasonable assumption since the paths are within the same building and have similar statistical characteristics ([2]). For each sample the cross correlation terms (ρ_{mn}) in the covariance matrix are calculated by taking the cosine of the angle difference between the two paths, as proposed in (2).

$$\mathbf{C} = \begin{bmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \cdots & \rho_{1N}\sigma_1\sigma_N \\ \rho_{21}\sigma_2\sigma_1 & \sigma_2^2 & & \vdots \\ \vdots & & \ddots & \\ \rho_{N1}\sigma_N\sigma_1 & \cdots & & \sigma_N^2 \end{bmatrix} \quad (3)$$

- The covariance matrix is factorised into lower and upper triangular matrices [9]. The upper triangular matrix represents the correlation weighting factor to be applied to the random sequences.

The above method was employed to synthesise shadowing profiles with the location of the transmitter and receivers as in the experiment. The results of the simulations are shown in Fig. 2b and Fig. 3b for both frequencies. As in the measured data, the spread of values is due to the fact that the number of samples used in each bin can only approximate stationarity. As seen in the measured correlation, the coefficients are strongly negative for large angles and become progressively more positive as the angle decreases.

4. Conclusions

The aim of the study was to propose a method for generating realistic shadowing profiles to be used within a channel model of the indoor environment. This is part of an investigation, carried out under the Mobile VCE programme, to simulate the relative performance of various radio architectures.

Two sets of measurements, one made inside an office building with a narrowband channel sounder at 2.4 and 5.2GHz and the other made on the indoor to outdoor interface with a wideband channel sounder at 2.45GHz, were presented.

Following this, a method is proposed to synthesise shadowing profiles, with desired auto- and cross-correlation statistics, based on a simple correlation function derived from data analysis.

The generated shadowing profile is derived from a model of the spatial relationship between the position of the mobiles and base stations within the building. Results from the simulation were compared with the measured data, which show good agreement in terms of both auto- and cross-correlation. The overall model presented is now in use within the Mobile VCE project as part of a system comparing the benefits of several innovative radio architectures for in-building coverage and capacity.

5. Acknowledgements

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6. Reference

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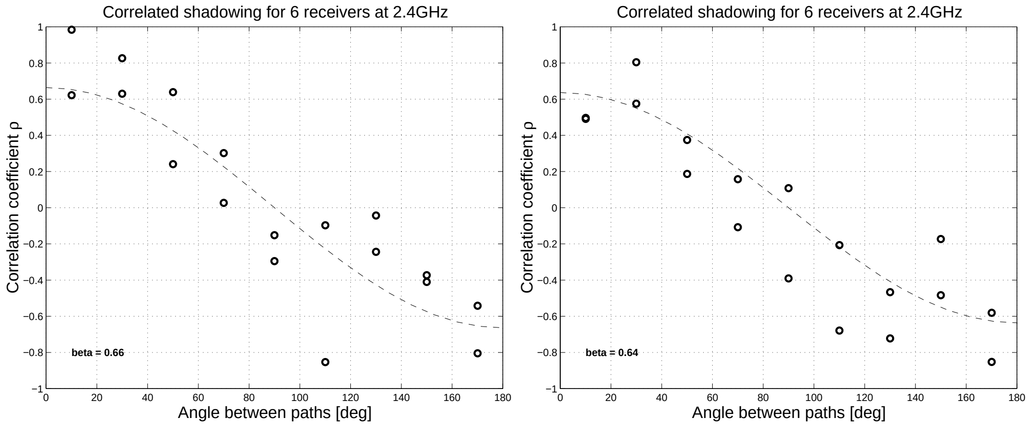
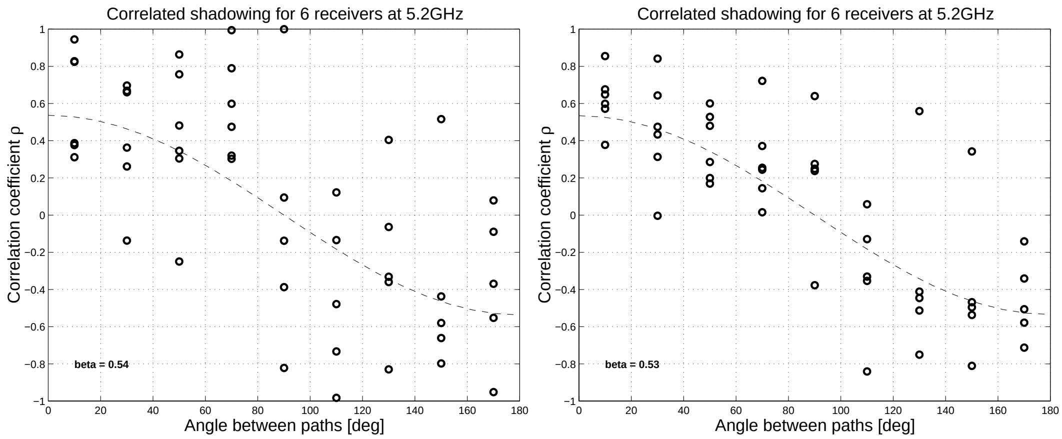


a) Measured b) Simulated

Fig. 2: Analysis of shadowing correlation for 2.4GHz



a) Measured b) Simulated

Fig. 3: Analysis of shadowing correlation for 5.2GHz

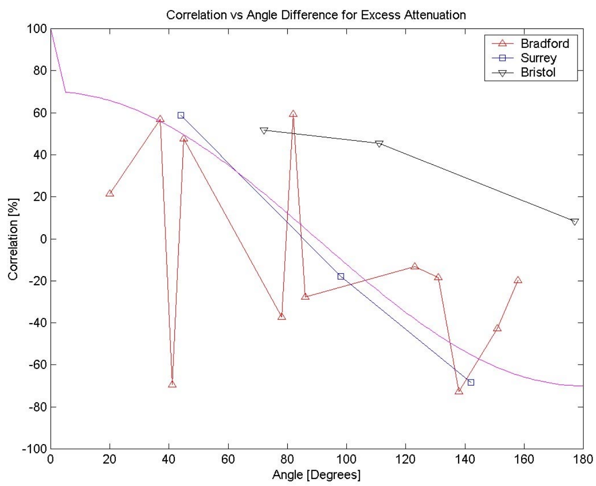


Fig. 4: Cross correlation results for wideband measurements