Impact of Shadowing Modelling on TD-CDMA System-level Simulations

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ABSTRACT

This paper presents a comparative analysis of system-level TD-CDMA simulation results obtained for different shadowing simulation models. Namely, relevance of aspects such as cross-correlation or spatial autocorrelation of shadowing is studied. It is shown that, in terms of system capacity, modelling of cross-correlation plays a more important role than spatial autocorrelation. Another relevant issue that arises from the analysis is the relevance of cross-link correlation in shadowing for a time-duplexing scheme such as TD-CDMA.

I. INTRODUCTION

The development of precise shadowing models is a key issue in system-level simulation of wireless networks, since it can significantly affect the dynamics of both signal and interference power variation at the receiving unit and, consequently, coverage area and received signal quality [1]. For instance, neglecting shadowing spatial autocorrelation present in wireless systems results in significant underestimation of both capacity and performance of techniques that strongly depend on radio link quality conditions [2].

The purpose of this paper is to analyse how the choice of a shadowing model affects capacity results of TD-CDMA system-level simulations. Time duplexing technique causes the network to undergo specific interference situations that are not present in frequency-duplexing systems such as GSM or WCDMA [3], for which the impact of shadowing modelling has already been analysed. This fact justifies the need for the study herein presented.

The structure of the paper is as follows: section II covers the description of different aspects of shadowing and their models, section III deals with the description of the TD-CDMA simulator, section IV presents the obtained simulation results and, last, section V summarises the conclusions.

II. SHADOWING MODELLING

A fair amount of work in shadowing modelling has been reported in the literature. Research has mainly been done in three directions:

- Finding a probability density function that suits statistical behaviour of shadowing processes.
- Modelling the relation between shadowing experienced by links from one point to two different sites.
- Analysing shadowing spatial autocorrelation function, or, in other words, modelling the relation between shadowing in links from one site to two different points.

A more detailed explanation of each aspect follows.

A. Probability density function

It is widely accepted that shadowing loss fits well a log-normal distribution (i.e. gaussian in dB) [4]. As for parameters of distribution, shadowing average is null (0 dB) and proposed values oscillate between 7 and 10 dB (e.g. [5]), depending on the selected simulation scenario.

B. Site-to-site cross-correlation

The existence of correlation between shadowing affecting links that have a common node has been recognised since the early work by Graziano [6]. This implies that shadowing processes correponding to links from one point to two different sites have a cross-correlation factor (ρ_{AB} in (1)) whose value is greater than 0:

$$\rho_{AB}(x_o, y_o) = \frac{E\left[L_A(x_o, y_o) \cdot L_B(x_o, y_o)\right]}{\sqrt{E\left[L_A^2(x_o, y_o)\right] \cdot E\left[L_B^2(x_o, y_o)\right]}} \quad (1)$$

where $L_A(x, y)$ means shadowing loss from site A to point (x,y). The simplest site-to-site correlation model consists in making such correlation factor equal to a fixed value, independently of the relative positions of sites A and B with respect to the point that is common to both links. A typical value of $\rho_{AB} = 0.5$ is common although 0.3 can also be used [7].

C. Spatial autocorrelation

Mobility of any of the elements of a wireless link implies shadowing changes along time that are closely related to changes in position. Therefore, even when a single link is modelled, there is a need to characterise its temporal evolution, which corresponds to a description of its dependence on spatial shift:

$$r(\Delta x, \Delta y) = \frac{E\left[L(x_o, y_o) \cdot L(x_o + \Delta x, y_o + \Delta y)\right]}{E\left[L^2(x_o, y_o)\right]} \quad (2)$$

where r is the autocorrelation factor. A pioneering work in this field is Gudmundson's model [8]. It approximates autocorrelation of shadowing as a exponential decay function whose parameters (ϵ and D) depend on the specific environment:

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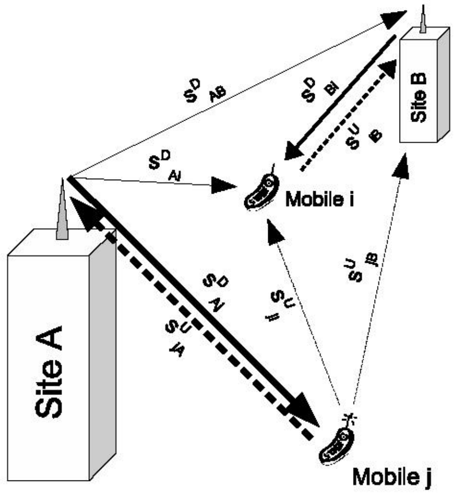

Fig. 1. Interference scenario in TDD systems.

$$r(t) = \epsilon^{-|v \cdot t/D|} \tag{3}$$

where v is speed and D is called "decorrelation distance". The main limitation of Gudmundson's model is that it only has one dimension, that is, distance is measured over mobile unit's trajectory. Therefore, it does not consider any correlation between different mobile units, no matter how close they might be. If that correlation is to be considered, then a two-dimensional model that relates inidvidual mobile trajectories to map coordinates is needed. An approach to extending Gudmundson's function to two dimensions, which consists in bi-dimensional filtering of uncorrelated random maps, is reported in [9].

D. Specific aspects of time-duplexing systems

In TDD systems, UTRA-TDD among them, both uplink and downlink share the same frequency band. This, along with the flexibility that 3GPP specifications give to radio resource management strategies, leads to interference scenarios fair different from those of FDD systems. Namely, interference does not only occur within the same link, but it also may happen between different links [3]. Figure 1 shows a typical TDD scenario with two sites (A and B) and two mobile units (i and j). Mobile i is served by site B whereas mobile j is served by site A. If interferences upon links between i and B are studied, the following types may occur:

- Uplink to uplink (UL-UL): s^U_{jB} interferring on s^U_{iB} if both uplinks share the same time slot within the TDD frame.
- Downlink to downlink (DL-DL): s^D_{Ai} interferring on s^D_{Bi} if both downlinks share the same time slot.
- Uplink to downlink (UL-DL): s^U_{ji} interferring on s^D_{Bi} if uplink jA and downlink Bi share the same time slot.
- Downlink to uplink (DL-UL): s^D_{AB} interferring on s^U_{iB} if downlink Aj and uplink iB share the same time slot.

While the first two are the same as in FDD systems and their behaviour is well-known, the other two are specific to TDD and they are not so well defined in the literature. For instance, cross-correlation of shadowing experienced by signals s^U_{jB} and s^U_{iB} in figure 1 has been widely analysed, (spatial autocorrelation, subsection II-C). The same can be said of correlation between shadowing in signals s^D_{Ai} and s^D_{Bi} (cross-correlation, subsection II-B). However, cross-correlation between shadowing in signals s^U_{ji} and s^D_{Bi}, and between s^D_{AB} and s^U_{iB} has not been described yet, though necessary to model [10]. For the sake of simplicity, UL-UL and DL-DL will be referred to as same-link interference hereon, whereas the other two cases will be named cross-link interference.

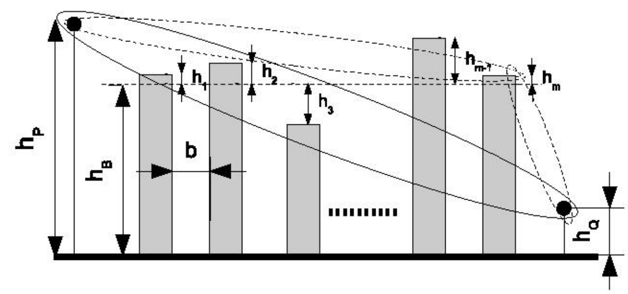

Fig. 2. Height variation profile obtained from sampling of matrix $\mathbf{H}$.

E. Multiple Diffraction Model

Within this subsection, we introduce a shadowing model capable of accounting for cross-link correlation. The model is based on previous works reported by Berg [11] and Saunders and Evans [12].

Let's suppose that we want to simulate a wireless network within an area of $R \times R$ (m^2) (the form of the area is assumed to be square without loss of generality). Let's also assume that for this area we have obstacles above which propagation occurs and the mean height of obstacles is h_B (m) while b (m) is their mean width. The first step of shadowing modelling consists in generating a random matrix $\mathbf{H}_{n\times n}$ with gaussian distribution [13] that simulates obstacle height variations around h_B for all the simulation area.

Now, let $P(x_p, y_p, h_p)$ and $Q(x_q, y_q, h_q)$ be two points within the simulation area between which shadowing is to be generated. In order to do so, a set of equally spaced samples $\{h_1, h_2 \ldots h_m\}$ between P and Q must be obtained from matrix $\mathbf{H}$. As a result, a profile of height variations around their mean value h_B is obtained (figure 2).

From [12], total loss due to obstacles can be written in decibels as the sum of the effects of each individual obstacle. In our case:

$$L_{diff} = \sum_{i=1}^{m} L_i\left(h_p, h_q, h_B, h_i, b, r\right) \tag{4}$$

where $h_B + h_i$ is obstacle height, r is propagation distance and the rest is as defined before. (4) becomes a path-loss model if $h_i = 0\ \forall i$. However, if there is any i for which $h_i \neq 0$, variations over path-loss model occur, thus shadowing appears. Assuming that height variations around their mean value are small and zero-averaged, (4) may be approximated as:

$$L_{diff} \approx \sum_{i=1}^{m} L_i|_{h_i=0} + \sum_{i=1}^{m} \left.\frac{\partial L_i}{\partial h_i}\right|_{h_i=0} \cdot h_i = L_0 + \sum_{i=1}^{m} w_i \cdot h_i \tag{5}$$

where the first term corresponds to the case where all parameters have their mean values, that is path-loss, and the second one corresponds to shadowing caused by the variability in obstacles. As expressed in (5), shadowing can be estimated as a linear combination of obstacle height variations along the propagation path whose. The main aspect of the model is how to find the appropriate values for w_i. In [12], authors propose to compute them as a function of the clearance of the first Fresnel zone between P and Q for the mean value of obstacle height.

The ability of the previously introduced model to account for cross-link correlation in shadowing come from the fact that it uses a single random matrix to produce all shadowing values for the simulation area, no matter the values of the antena heights. Therefore, when simulating, for instance, shadowing in signal s^D_{Bi} (recall figure 1) mobile's surrounding obstacles are modelled the same as when simulating shadowing in s^U_{ji}, hence correlation in both values is present.

III. Simulator description

In order to assess the performance of shadowing models on UTRA-TDD performance, simulations have been carried out for shadowing: (a) uncorrelated, (b) cross-correlated with fix correlation factors, between 0.3 and 0.5, (c) spatially autocorrelated with no cross-correlation and (d) generated using the abovementioned multiple diffraction model. It must be highlighted that a mix model considering both cross and autocorrelation has not been simulated so as to be able to isolate effects. Within this section the main aspects of the simulator are described.

A. Layout

A simple radio network layout consisting in two sites covering a rectangular area has been chosen (fig. 3). Each site has only one cell with an isotropic antenna. Radio interface is as UTRA-TDD, it consits of frames of 15 slots within which up to 16 simultaneous users can be multiplexed. Each slot may be assigned to either up or downlink.

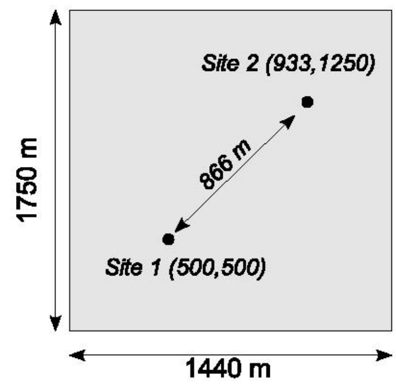

Fig. 3. Simulated layout.

TABLE I
STANDARD DEVIATION OF SIMULATED SHADOWING

Mobile to mobile	5 dB (LOS), 10 dB (NLOS)
Site to site	0 dB *(only one link is simulated)*
Site to mobile	8 dB

B. Propagation

Another consequence of the specific interference scenario of TDD is the need for three different path-loss models:

- Mobile to mobile
- Site to site
- Site to mobile

For this study we have chosen the same path-loss models as in [14], appropriate for urban environments.

As for shadowing, it has been modelled for UL (s^U_{iB}, s^U_{jB}... in figure 1) and DL (s^D_{Ai}, s^D_{Bi}...) by generating shadowing maps, as in [9]. For s^D_{AB} and s^U_{ji} non-correlated shadowing is generated, except in the case of the *multiple diffraction model* that intrinsically accounts for correlation. Such lack of correlation is justified by the fact that considering it would make shadowing generation a computationally-expensive four-dimensional problem. Standard deviation values are in table I.

C. Admission control

Admission control in uplink consists in estimating the required received power for the incoming call and, with such estimate, computing the level of expected noise plus interference. This is usually called "noise rise" and is calculated as follows:

$$\nu = \frac{N_0 \cdot W + I}{N_0 \cdot W} \tag{6}$$

where N_0 is background noise spectral power density, I is interference power and W is bandwidth. If this level is above a certain threshold, then the call is rejected, otherwise, it is accepted. A similar scheme is set for the downlink, where the threshold is applied to the level of transmitted power, instead of noise rise.

D. Slot allocation strategies

Since this is not the main concern of this work, we have selected two slot simple allocation criteria, among the ones reported in [15] (figure 4):

- Ordered allocation (OA): first slots in the TDD frame are allocated to downlink whereas last ones are assigned to uplink. Before an empty time slot is assigned it is checked that the new call cannot be admitted in a partially loaded slot. All cells follow the same order of allocation.
- Random allocation (RA): any time slot can be assigned to any link. However, as in OA, an empty time slot is only allocated if the new call cannot be admitted in a partially loaded slot.

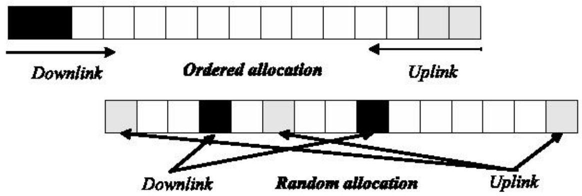

Fig. 4. Ordered and random slot allocation strategies.

TABLE II

SIMULATION PARAMETERS

Maximum UE Tx power	30 dBm
Maximum Node B Tx power	34 dBm
Noise density power	-174 dBm/Hz
Orthogonality factor (DL)	0.9
Joint detection efficiency (UL)	70%
Noise rise thres. (Call admis.)	6 dB
Downlink power thres. (Call admis.)	$75\% \cdot P_{MAX}$

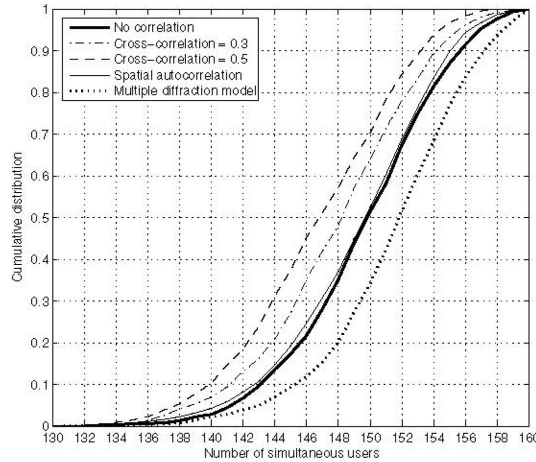

Fig. 5. Cumulative distribution of achievable capacity in terms of simultaneous users.

These schemes, though rather simplistic, cause the network to experience very different percentages of slots with cross-link interference. While the first one produces a low probability of crossed links in the same slot, the second one greatly increases such probability, since slot allocation is uncoordinated. As it will be seen later, this difference has a great impact on the requirements for a shadowing model.

E. Other aspects

Simulation proceeds as follows: a new call is randomly generated with a uniform distribution within the simulation area; after that, cell selection is carried out based on propagation loss and, if the new call is admitted, perfect power adjustment begins. If the result of the admission control process is negative, the call is rejected. In power control process neither mobiles nor site transmitters are allowed to transmit more than their maximum power. Simulation is repeated 1,000 times (snapshots) and for each snapshot 200 calls are attempted. Hence, a distribution of achieved cell capacity in terms of number of simultaneous users can be generated.

Values for main simulation parameters are in table II:

It is important to notice that the actual simulation results will greatly depend on the choice of some of these parameters, as well as on the specific call admission or outer power control schemes . For instance, if noise rise threshold is low network resources will be considered to be full in a short time and many service demands will be blocked. However, if such parameter is high then there is a risk of network saturation in power adjustments. In our case, absolute results are not as important as the comparison between them. Therefore no work on parameter optimisation is reported herein.

IV. RESULTS

Figure 5 depicts the cumulative distribution of the maximum number of simultaneous users in the system for each shadowing model. Time slot allocation criteria has been (OA) in this case, thus giving a very low probability of cross-link interference. Specifically, the obtained probability of crossed links is 2.99% of slots. The graph shows that for this case there is no significant performance difference between non-correlated shadowing and shadowing with spatial autocorrelation. Consequently, it may be deduced that while autocorrelation has a noticeable impact on link quality [2], it has little effect on network capacity if link-adaptation techniques are not simulated.

On the other hand, the figure also shows that greater values of cross-correlation factor of shadowing lead to a reduction in capacity and that the multiple diffraction model provides significant capacity gain over the rest of models. Figure 6 intends to illustrate the reason for this behaviour. This figure shows the cumulative distribution of the difference in propagation losses from each point within the simulated area to both sites, $\left|L(s^D_{Ai}) - L(s^D_{Bi})\right|$, where L means path loss plus shadowing. It can be appreciated how an increment in cross-correlation has the effect of increasing the probability of low difference, thus reducing the number of points in the map with either very high or very low carrier to interference ratios. This produces a reduction on the relative number of mobiles with good signal quality admitted in the system while the amount of mobiles with similar propagation losses to both cells grows, hence the capacity reduction due to an increase on the amount of power needed to compensate these not-so-good propagation conditions. On the contrary, simulation of spatial autocorrelation has little effect on this distribution and, consequently, little effect on capacity. Last, multiple diffraction model tends to slightly increase mean loss difference, hence the capacity gain.

Figure 7 depicts the same plot as figure 5 but for the case of random slot allocation. Besides the lower capacity such allocation scheme allows, as reported in [14], a significative difference to the previous case is the reduction in the separation between the distributions. That is, there is less reduction

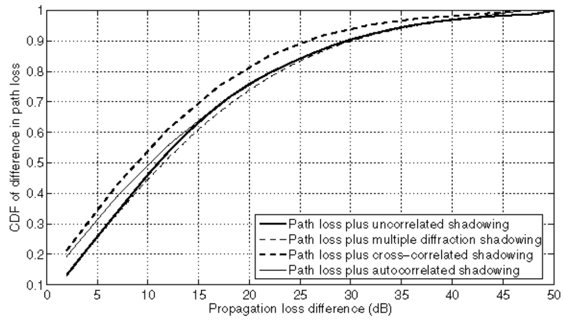

Fig. 6. Change in propagation and interference conditions as a result of shadowing cross-correlation.

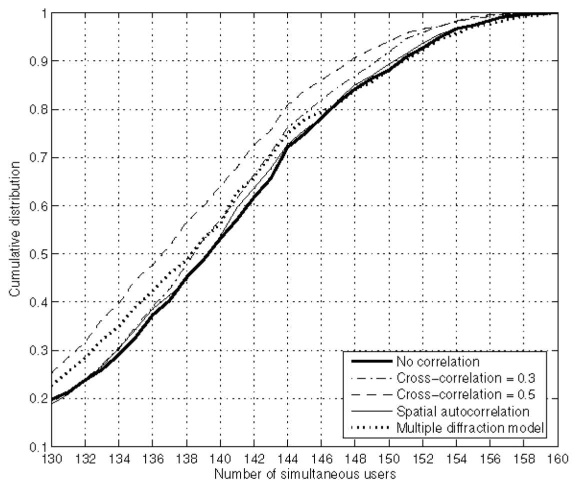

Fig. 7. Cumulative distribution of number of simultaneous users for random slot allocation.

in capacity when simulating cross-correlation in shadowing relative to the case in which such correlation is ignored. The reason for this is the increased portion of cross-link slots (21.8%). Since cross-link shadowing correlation is not modelled in any of these models, its effect is not present in results. However, multiple diffraction model is able to account for such correlation and, as a consequence, it produces a greater reduction in capacity, since modelling of cross-correlation tends to have a negative impact on capacity, as seen before. Namely, while simulation results for multiple diffraction model present a reduction in capacity from OA to RA of 9.0%, for the rest of cases such reduction varies between 6.7% and 7.4%.

V. Conclusions

This paper has presented an analysis of shadowing modelling impact on performance of TD-CDMA system-level simulation in terms of network capacity. Results indicate that cross-correlation has a relevant impact on achievable capacity and it should therefore be considered when modelling networks. On the contrary, the relevance of shadowing autocorrelation for these results is much lower, consequently, it may be omitted without loss of validity on the results provided that link evolution is not simulated.

Also, a different approach to shadowing modelling named multiple diffraction model has been tested. The interest of such model relies on its ability to model cross-link correlation of shadowing. It has been shown that modelling of this aspect has some impact on network performance.

Finally, it must be stated that although no definite conclusion can be obtained concerning which is the best choice, since this should be tested against measurements, this work has clearly shown that the best option should consider both same-link and cross-link cross-correlation in shadowing.

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