Effect of Shadowing Correlation Modeling on the System Level Performance of Adaptive Radio Resource Management Techniques

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***Abstract*— The use of software emulators to evaluate complex mobile communication systems is becoming increasingly useful and common. To conduct a valid and accurate study, the models employed in such simulators need to be carefully selected. On the other hand, increasing the complexity of such models in situations in which they do not affect or interact with the particular technique under study only contributes at increasing the simulator's implementation and simulation costs. In this context, this work aims at evaluating the impact of considering different types of correlation when developing shadowing models for system level investigations. For that purpose, Link Adaptation, an adaptive radio resource management technique, has been considered as a case study.**

Keywords – shadowing modeling, shadowing correlation, system level modeling, radio resource management, link adaptation.

I. INTRODUCTION

As complexity of mobile communication systems increases, the use of computer simulations to assess the performance of new techniques is becoming increasingly common. Although this evaluation methodology represents a good compromise between cost, time efficiency, accuracy and complexity, a careful selection of the simulated models is required to provide an appropriate and accurate evaluation of any new technique or algorithm.

Mobile radio channel propagation is typically modeled as the combination of three effects: mean path loss, shadowing and fast fading. Shadowing is usually approximated by a lognormal law. To consider the spatial correlation properties of the shadowing, Gudmundson [1] suggested a one-dimensional model of its autocorrelation function. Although this model has been extensively used in mobile communications testbeds and simulation studies [2], it is limited in the sense that it independently estimates the shadowing for each mobile unit. This approach results in the shadowing experienced by receiving units that are in close vicinity being uncorrelated even if their surrounding obstacles are identical. As observed in different measurement campaigns (e.g. [3] and [4]), such lack of correlation does not happen in real networks. Neglecting the potential shadowing correlation present in wireless systems can become important when evaluating the performance of techniques that strongly depend on the radio link quality conditions (e.g. soft handover, macro-diversity and link adaptation). To overcome the above-mentioned modelling limitation, different studies (see e.g. [5]) have proposed bi-dimensional shadowing models that allow generating correlated shadowing values for neighboring mobile units.

Another aspect of shadowing that is also usually neglected in models is cross-correlation of signals coming from different base stations. However, some studies (e.g., [3] and [4]) have actually shown that such cross-correlation can be present in real systems. This is due to the fact that the random component of the dB loss consists of the sum of two components: one resulting from obstacles in the vicinity of the receiving unit and a second one from the specific surroundings of each base station. As a result, the fading phenomena that affect different signals received by a user from surrounding base stations might experience some correlation. Studies such as [3] and [4] claim that the shadowing cross-correlation depends upon the geometrical angle between the different considered links. Other studies based on experimental analysis (e.g., [6]) maintain that this correlation also depends on the relative distance between base stations. However such claims have been sometimes questioned, like in the work reported in [7], and a fixed 0.5 cross-correlation for any couple of base stations is generally included in simulations studies ([8], [9]).

In order to justify the inclusion of complex propagation models in system-level studies, it is important to demonstrate that their use will produce a significant effect on the outcome of such studies. In this context, the aim of this work is to assess the impact of considering both spatial correlation and site-to-site cross-correlation in the shadowing models when conducting system-level investigations. For that purpose, the analysis of Link Adaptation (LA) is considered as a case study, because the operation of this adaptive Radio Resource Management (RRM) technique is highly dependent on channel quality variations.

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II. SHADOWING MODELING

A. Lognormal Model

The effect of shadowing is commonly modeled by adding a log-normally distributed, that is, normally distributed in decibel domain, random variable to propagation path loss.

However the simple addition of a gaussian variable does not completely model shadowing. An additional aspect is usually considered: shadowing is a slowly variant characteristic of radio channel. This slowness in variations indicates the existence of a non-zero autocorrelation of shadowing in time domain. As mobility is assumed, time correlation is intimately related to space correlation. Spatial correlation of shadowing is mathematically modelled by [1]:

$$R(\Delta r) = e^{-\ln 2 \cdot \frac{\Delta r}{d_{corr}}} = 2^{-\frac{\Delta r}{d_{corr}}} \quad (1)$$

where Δr is the space shift (change in position) and d_{corr} is the decorrelation distance, typically equal to 20 meters.

The so-called lognormal model includes this spatial correlation which is independent for each user even if two of them coincide physically in the same point.

B. Two Dimensional Model for Spatial Correlation

Let's consider the case in which a series of propagation maps that account for shadowing needs to be generated. This task involves producing a shadowing sample for each location in every map. Since maps are two-dimensional, it is not possible to establish an order among its locations. Equation (1) provides a one-dimensional form for shadowing autocorrelation that implies one-dimensional filtering. An extension to the two-dimensional case is hence needed.

The first step towards the extension of the model is changing the form of the autocorrelation function. In a two-dimensional map a pair of Cartesian coordinates (x,y) unambiguously identifies a unique location. Movement from one point (x_1,y_1) to another (x_2,y_2) can, therefore, be described as a pair of increments, each corresponding to one coordinate: $(\Delta x, \Delta y) = (x_2 - x_1, y_2 - y_1)$. Hence, distance between both points is $\Delta r = \sqrt{\Delta x^2 + \Delta y^2}$. Now, it becomes evident that equation (1) can be transformed in its two-dimensional counter-part:

$$R(\Delta x, \Delta y) = e^{-\ln 2 \cdot \frac{\sqrt{\Delta x^2 + \Delta y^2}}{d_{corr}}} = 2^{-\frac{\sqrt{\Delta x^2 + \Delta y^2}}{d_{corr}}} \quad (2)$$

where Δx and Δy are the shift in map horizontal and vertical coordinates (therefore, they are measured in distance units).

Next the filter design problem to achieve the autocorrelation properties needs to be undertaken. This can be realized using the following well-known identity that takes profit of Fourier transform and linear filter properties:

$$\left|F\left[R(x,y)\right]\right| = \left|H\left(f_x, f_y\right)\right|^2 \quad (3)$$

that is, when a signal is obtained by filtering a white (flat spectrum) input, the modulus of the Fourier transform of the autocorrelation function of that signal equals the square of the filter frequency response modulus.

From equation (3), considering a phase for $H(f_x, f_y)$ equal to that of $F[R(x,y)]$, the inverse Fourier transform can be applied so as to obtain the filter impulse response $h(x,y)$. Last, it also must be considered that the filter should not alter the variance of shadowing. Hence, normalisation of filter coefficients is necessary.

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h^2(x,y) \cdot dx \cdot dy = 1 \quad (4)$$

This two dimensional shadowing model provides bi-dimensional shadowing maps for each base station included in the cellular layout; each map covering the entire simulation area.

It's work noticing that these shadowing maps include only the spatial correlation and do not take into account the site-to-site cross-correlation effect which is assumed to be equal to zero.

C. Two Dimensional Model with Spatial and Base Station Correlation

Now, let's assume that propagation from a certain point to a set of n different base stations must be modeled, as is usually the case in system-level simulations. Since shadowing is due to the influence of local topographic features and man-made structures, it is reasonable to think that there must be certain correlation between shadowing corresponding to different base stations at the same location. Therefore, the previous model needs to be extended

The procedure to generate the shadowing maps with spatial and BS correlation is as follows: first of all, if n base stations are taken into account, the model generates n+1 matrices $\{g_0, g_1, .. g_n\}$. The first matrix becomes the common shadowing component while the rest of maps model the base-station-dependent component. Every element of each 2D map is a non-correlated lognormal value with zero mean and standard deviation equal to σ and corresponds with a physical location in the simulation area. Using the common map g_0, the model produces two cross-correlated shadowing maps (G_i, G_j) by means of the next equation.

$$G_i = \rho^{1/2} g_0 + (1-\rho)^{1/2} g_i ;\ G_j = \rho^{1/2} g_0 + (1-\rho)^{1/2} g_j \quad (5)$$

where ρ could be defined for each pair of maps (G_i, G_j) either as a fixed value or as a variable correlation factor dependent on the geometrical angle and relative distance between both base stations in each specific position on the map.

The last step regards the introduction of the 2D spatial autocorrelation following the same procedure as previous subsection.

III. EVALUATION ENVIRONMENT

A. System level simulator

In order to ensure high accuracy and to account for sudden channel quality variations, this research has being conducted using an event-driven simulator working at the burst level and emulating packet-data transmissions in a GPRS-like system [10]. The simulator represents the dynamic behavior of the channel quality in terms of the Carrier to Interference Ratio (CIR) and considers the interference produced by the first and second tier of co-channel interferers. The pathloss (Okumura-Hata), shadowing and fast fading effects have been included.

The simulator concentrates on the downlink performance and models a cellular network of equally sized 3-sector macro cells with a cluster size equal to four. Although mobility has been implemented, handover between sectors has not been considered. The boundary effects have been removed by using a wrap-around technique.

The emulator implements three different traffic sources: H.263 video, email and WWW browsing[1]. No channel partition has been applied between the different services. The WWW and email traffic sources have been implemented as ON/OFF models. For both traffic models, the transmission of a new packet can not start until the previous transmission has finished, i.e. all the data has been correctly received. The active transmission time will hence depend on the channel quality conditions. The H.263 video traffic model considered employs three different frame types, namely I, P and PB, and targets a bit rate of 16 Kbit/s. Since real-time video transmissions are considered, no ARQ protocols have been implemented for H.263.

In order to reduce the complexity of system level simulations, the effects at the physical layer are generally included by means of Look-Up Tables (LUTs). Following the indications provided in [11], an advanced link-to-system level interface working at the burst level has been considered. This interface, composed of two different types of LUTs, is able to include the effect of fast fading at the system level. Detailed information on the employed link-to-system level interface can be found in [11].

B. Link Adaptation

To analyze the effects of shadowing correlation modeling on the system level performance and operation of mobile communication systems, Link Adaptation has been selected as a case study. LA is an adaptive RRM technique that aims to efficiently use the scarce available radio resources by dynamically changing the employed transport mode (i.e. modulation and coding scheme) based on the experienced channel quality conditions. The work reported in [11] already demonstrated the importance of an appropriate fast fading model to extract accurate and valid conclusions regarding the operation and system performance of LA. In this context, it has then been considered that LA represents a suitable and sensitive candidate to evaluate whether modeling the different correlation components that might be present in shadowing has a considerable effect on the system performance of mobile communication systems.

The GPRS standard defines four different coding schemes with different error correction capabilities. While CS1 corresponds to the more robust coding scheme, CS4 does not consider any error protection. As a result, the different GPRS coding schemes offer a trade-off between throughput and coding protection, paving the way for the application of dynamic LA to GPRS. As previously explained, the basis of LA is to adaptively select the optimum CS according to the channel quality conditions. In this work, a CS is considered to be optimum if it maximizes the throughput [12] and the LA algorithm estimates the most suitable CS each 20ms[2].

IV. SYSTEM PERFORMANCE

In order to demonstrate the impact that modeling the shadowing correlation might have on the system level performance of adaptive radio resource management techniques, this section compares the operation and performance of Link Adaptation considering the three following shadow models: lognormal shadowing model with one-dimensional spatial correlation, bi-dimensional shadowing maps with spatial correlation but without site-to-site cross-correlation and bi-dimensional shadowing maps with spatial and site-to-site cross-correlations. For the last case, a fixed 0.5 site-to-site cross-correlation has been considered.

Fig. 1 compares the system[3] throughput performance, by means of a cumulative distribution function, that would be obtained using the three different shadowing models. The figure clearly shows that using simpler shadowing models results in an underestimation of the system-level performance that could be obtained when employing LA. Such underestimation is a consequence of neglecting the inherent spatial and site-to-site correlation present in the shadow fading. Since LA bases its transport mode selection on the experienced channel quality conditions, its operation is improved when such conditions are correlated. This improved operation reflects in a higher percentage of RLC blocks transmitted using the optimal coding scheme and a lower number of coding scheme changes per second[4] (see Table I). In particular, for the scenario reported in Fig. 1, a 23% reduction in the average number of CS changes per second requested by LA has been observed when representing the shadowing with a bi-dimensional map including spatial and site-to-site cross-correlation compared to when it was modeled as a lognormal distribution. The use of bi-dimensional shadowing maps also results in an 9.5% increase in the proportion of RLC blocks received with the optimal CS compared to when modeling the shadow fading as a lognormal distribution.

[1] The following mixed scenario has been considered in this paper: 6 web users, 4 email users and 6 H.263 users.

[2] This interval is the minimum possible since it corresponds to the time necessary to transmit a Radio Link Control (RLC) block.

[3] That is considering the three different traffic user types.

[4] The average number of CS changes per second provides an indication of the signaling load associated with the use of LA.

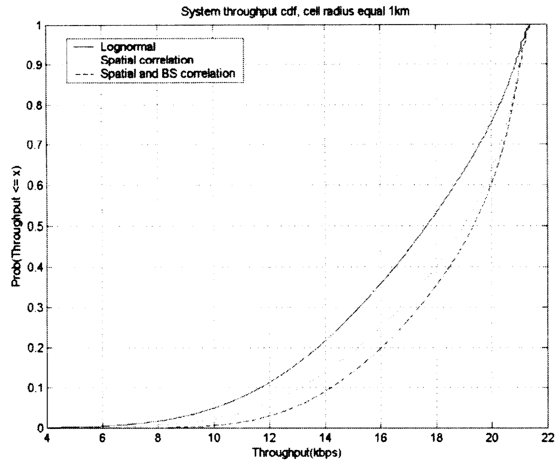

Figure 1. System throughput cdf (20ms LA updating period, load of 16 users per sector and cell radius of 1km)

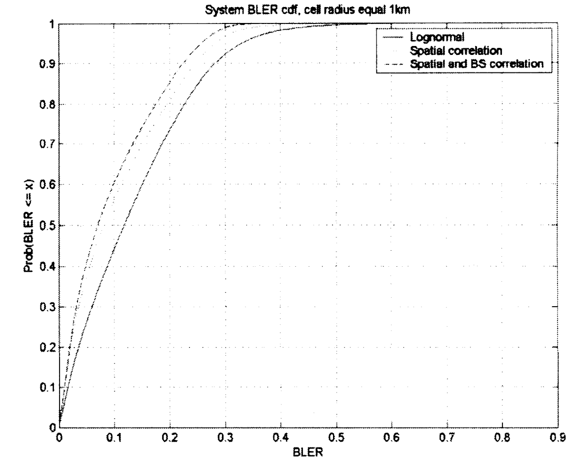

Figure 2. System BLER cdf (20ms LA updating period, load of 16 users per sector and cell radius of 1km)

TABLE I. LA SYSTEM OPERATION FOR DIFFERENT SHADOWING MODELS (1KM CELL RADIUS)

	Lognormal	Spatial correlation	Spatial and BS correlation
Optimal CS (%)	72.85	77.5	79.74
Wrong-side failures[5] (%)	13.59	11.25	10.13
Mean CS changes per second	13.17	11.24	10.17

As illustrated in Fig. 2, the improved LA operation under higher correlated channel quality conditions results in lower error transmission rates (BLER, Block Error Rate). Such reduced error rates are at the origin not only of the previously illustrated higher system throughput performance but also of the lower experienced normalized delay; see Table II.

Table III highlights an interesting observation, that is, that the shadowing correlation has a quite varying effect for each traffic user type. In particular, the results shown in Table III indicate that the service that is mostly affected, in terms of performance, by an inaccurate modeling of the inherent correlation present in the shadow fading is H.263 real-time video transmissions. The underestimated H.263 throughput performance obtained with simple shadow fading models considerably affects the operation of LA (average number of CS changes per second) and the user perceived real-time quality of service. For example, while only 39.35% of video frames are transmitted without delay[6] and with a BLER below 5% when modeling the shadowing with a lognormal distribution, this value increases to 47.03% when considering bi-dimensional shadowing maps including spatial correlation and to 49% when employing bi-dimensional shadowing maps including spatial and site-to-site cross-correlation. The higher impact of the shadowing correlation on the H.263 real-time video traffic source is probably due to its less bursty nature compared to WWW or email users. In fact, with the considered H.263 traffic source and the offered GPRS data rates, H.263 video frames are constantly generated and transmitted. As a result, their radio transmission performance can be considerably affected by the presence or absence of correlation on the experienced channel quality conditions.

The previously reported results have demonstrated the significant impact that spatial shadowing correlation can have on the system level performance and operation of adaptive RRM techniques. Moreover results have also shown that the effect of site-to-site shadowing cross-correlation must be considered too since its effect on the final system performance is not negligible.

TABLE II. AVERAGE SYSTEM PERFORMANCE FOR DIFFERENT SHADOWING MODELS (1KM CELL RADIUS)

	Lognormal	Spatial correlation	Spatial and BS correlation
Throughput (kbps)	16.89	17.93	18.40
BLER (%)	13.95	11.03	9.82
Normalized delay (ms/kbit)	69.71	65.77	63.72

TABLE III. THROUGHPUT PERFORMANCE IN KBPS FOR EACH TRAFFIC TYPE (1KM CELL RADIUS)

	Lognormal	Spatial correlation	Spatial and BS correlation
WWW	17.43	17.98	18.45
Email	17.44	17.94	18.37
H.263	15.79	17.86	18.38

[5] A wrong-side failure corresponds to the case where a user is using a non-optimal CS that is also not robust enough for correct reception.

[6] Since we are considering real-time services, a video frame is discarded if it is not completely transmitted by the time a new video frame is generated.

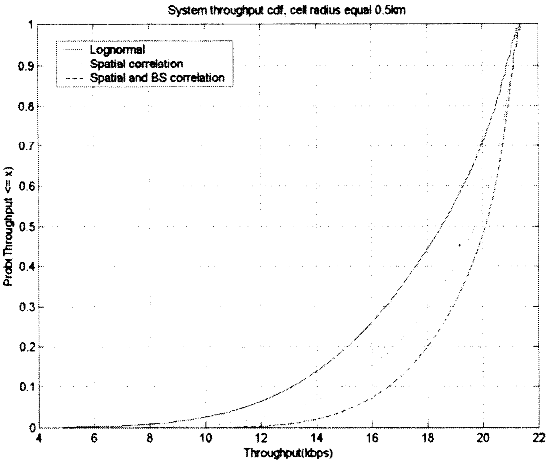

Figure 3. System throughput cdf (20ms LA updating period, load of 16 users per sector and cell radius of 0.5km)

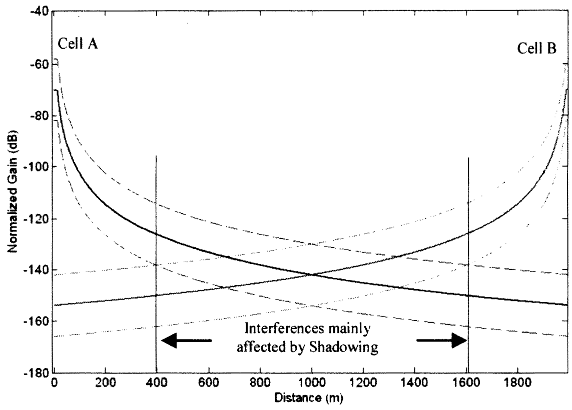

Figure 4. Area of greater effect of shadowing on the experienced carrier-to-interference ratio

Fig. 3 shows that the effect of the site-to-site shadowing cross-correlation on the LA system performance increases with lower cell radius; Fig. 3 plots the system throughput cdf considering a cell radius of 0.5 km and the same operating conditions as in Fig. 1[7]. For example, under the scenario corresponding to Fig.1, there is a difference of 5.6% on the higher throughput experienced by 20% of the samples when considering bi-dimensional shadowing maps with spatial and site-to-site cross-correlation compared to when only considering spatial correlation. This difference increases to 7.2% under the operating conditions corresponding to Fig. 3. Such increase is due to the fact that when considering higher cell radius, the distance between interferers can be significant. In this case, the dominant factor in the experienced CIR, and therefore in the finally user perceived quality of service, is the path-loss instead of shadowing. This effect is illustrated in Fig. 4. As distance between interferers increase the relative size of the area in which CIR is highly dependent on shadowing decreases and vice versa. Within this area modeling cross-correlation implies reducing the probability of heavy interference, hence increasing capacity. Consequently, when the cell radius diminishes a shadowing cross-correlation model has greater impact on system performance.

V. CONCLUSIONS

This paper has presented a comprehensive 2D shadowing model, which incorporates both spatial auto-correlation and site-to-site cross-correlation. The performance of the proposed model has been evaluated and a significant impact on the system performance estimation has been identified. Specifically adaptive RRM techniques such as LA have shown to be very sensitive to the level of correlation of shadowing. Simulations have demonstrated that the site-to-site cross-correlation has a remarkable impact especially when reduced radii are taken into consideration. Consequently a highly-accurate shadowing model has to be selected when carrying out system simulations in order to obtain valid results.

[7] Figures 1 and 3 also consider the same fixed BS transmitting power.

Further work on the evaluation of more detailed cross-correlation modelling will be carried out considering also the relative distance between the base stations and the geometrical angle.

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REFERENCES

[1] M. Gudmundson, "Correlation model for shadow fading in mobile radio systems", Electronics Letters, vol. 27, pp. 2145 2146, November 1991.

[2] ETSI, "Selection procedures for the choice of radio transmission technologies of the UMTS", 1998.

[3] V. Graziano, "Propagation correlations at 900 MHz", IEEE Transactions on Vehicular Technology, vol. 27, pp 182 189, November 1978.

[4] J. Van Rees, "Cochannel measurements for interference limited small cell Planning", Arch. Elek. Ubertragung., vol. 41, pp 318 320, 1987.

[5] R. Fraile, J. Gozálvez, O. Lázaro, J. Monserrat and N. Cardona, "Effect of a Two Dimensional Shadowing Model on System Level Performance Evaluation", Proceedings of the International Symposium on Wireless Personal Multimedia Communications, WPMC2004, September 2004.

[6] S. Saunders "Antennas and Propagation for Wireless Communication Systems Concept and Design", Wiley, 1999.

[7] T. J. Lowe, J. Weitzen, "Isolation and Analysis of the Log-Normal Shadowing Component at 1900 MHz", Proceedings of the IEEE Vehicular Technology Conference, pp 791-796, September 2000.

[8] A.J. Viterbi, A.M. Viterbi, E. Zehavi, "Other-cell Interference in Cellular Power-controlled CDMA", IEEE Transactions on Communications, vol. 42, pp 1501-1504, February 1994.

[9] Harri Holma and Antti Toskala, "WCDMA for UMTS: radio access for third generation mobile communications", John Wiley & Sons, 2001.

[10] J. Gozalvez and J. Dunlop, "On the Dynamics of Link Adaptation Updating Periods for Packet Switched Systems", WPMC2001.

[11] J Gozalvez and J Dunlop, "Link Level Modelling Techniques for Analysing the Configuration of Link Adaptation Algorithms in Mobile Radio Networks", Proceedings of European Wireless 2004, pp 325-330, February 2004.

[12] ETSI-SMG, "EDGE Feasibility study, Work item 184; Improved Data Rates through Optimized Modulation", Tdoc 97-331, December 1997.