Wang, Z., Tameh, E. K., Nix, A. R., & Gasparini, O. (2004). A joint shadowing process model for multihop/ad-hoc networks in urban environment. In Wireless World Research Forum (11th : 10-11 June 2004 : Oslo, Norway). (pp. 1 - 10)

A Joint Shadowing Process Model for Multihop/Ad-hoc Networks in Urban Environment

Zhenyu Wang   Eustace K. Tameh   Andrew R. Nix   Otello Gasparini
E-mail: Zhenyu.Wang@bristol.ac.uk (Zhenyu Wang) Tek.Tameh@bristol.ac.uk (Eustace Tameh)
Andy.Nix@bristol.ac.uk (Andrew Nix) Gasparini@dune.191.it (Otello Gasparini)

***Abstract* – For multihop/Ad-hoc networks, the conventional one-dimensional (1-D) channel model cannot capture the spatial correlation of the shadowing processes. This paper investigates the joint spatial/temporal correlation property the shadowing process for peer-to-peer radio links in urban environments. Statistical analysis reveals that the shadowing process is mainly a result of the movement at the mobile station (MS) side. Furthermore, the joint correlation property of the MS-MS channel shows that MS movement at each end of the peer-to-peer link have independent and equal effect on the correlation coefficient. A filter based joint shadowing process simulation model is proposed for urban peer-to-peer radio channels. Simulations illustrate the potential of the proposed channel model.**

***Index Terms*—Channel model, shadowing, spatial correlation, multihop, Ad-hoc, urban.**

I. INTRODUCTION

The demand for flexible mobile multimedia services continues to grow. Traditional cellular solutions are coming under increasing pressure from peer-to-peer WLAN solutions such as 802.11b. Beyond third generation networks are looking to combine peer-to-peer connectivity together with traditional cellular solutions to improve coverage, reduce transmit power, and ultimately provide ubiquitous high capacity connectivity. This area has been widely studied and a number of wireless systems that explore adaptive self-configurable networks over peer-to-peer radio channel have been proposed [1-5]. To evaluate the performance of such systems in an urban setting, proper radio propagation models for peer-to-peer links that can provide all the essential channel characterizations are necessary. Among those channel characterizations, the spatial/temporal correlation properties of shadowing attract considerable interest in the field of multihop/ad-hoc networks. One of the core ideas here is to provide high capacity connectivity by overcoming the heavy shadowing and more efficiently reusing the radio resource spatially [1,3].

Most existing channel models [6,7] are established based on the base station to mobile station propagation channel for cellular networks, where only the auto-correlation of the Base-station to Mobile Subscriber (BS-MS) is modelled. A two-dimensional (2-D) sum of sinusoids (SOS) based channel model is developed in [8] to simulate the BS-MS shadowing process in a virtual map. In [9], the cross-correlation of MS to multi BS links is modelled for handoff performance studies. However, in a multihop/ad-hoc network, the shadowing correlation between a large number of MS-MS links needs to be closely investigated. [10] reported that incomplete consideration of the spatial correlation in multipoint-to-multipoint (M2M) radio channels (i.e. multiple MS-MS links) can lead to significant inaccuracies in simulation results, especially for the routing protocols and radio resource management (RRM) performance evaluations. A simple biased fading (random or site-specific) process applied to each MS is suggested in this paper. In [11], a general mathematical joint correlation model for shadow fading between two BS and two MS is derived. However, this model is unable to be extended for M2M channels.

In this paper, the spatial correlation properties between MS-MS links have been investigated, as well as for other links existing in a multihop network, e.g. BS-MS, BS to fixed Relay Node (BS-RN), RN-MS, RN-RN. The joint correlation function is extracted and a filter based shadowing process model is proposed. The performance of the proposed channel simulator is analyzed in terms of the autocorrelation function of the simulated shadowing process. Simulations illustrate the potential of the proposed channel model. This model, incorporating the statistical channel model developed in previous study [12], provides a complete solution for power prediction in system level simulations that incorporate multihop/ad-hoc and fixed relay network elements in an urban environment at UHF/VHF frequency band.

The remainder of this paper is organized as follows: In section II, the 3-D ray model used to obtain the channel data is introduced together with the simulation settings; the data analysis and extracted joint correlation function is given in section III; in section IV, the proposed shadowing model is described; finally, the performance of the proposed model is analyzed in section V and some concluding remarks are drawn in Section VI.

II. Ray Model Simulation

As it is extremely difficult to obtain sufficient data samples by means of measurement due to the need to measure all mesh links between MSs, BSs and RNs, the shadowing correlation is analysed based on the data generated from a fully three-dimensional deterministic propagation model [13]. This model uses geographic data (terrain, building, foliage and ground cover data) to predict power as well as time, frequency and spatial dispersion in the radio channel. The model was developed at the University of Bristol and has been validated for transmitter (TX) locations both above rooftop and below rooftop in urban environments at 2GHz and 5GHz [14,15]. In the Bristol comparison, the mean error of the predicted power was less than 4.5dB and the rms. error was less than 7.5dB.

Simulations are conducted on a 1.4km x 1.4km area of central Bristol (Figure 1). The urban environment is typical of a European city with buildings typically 3 storeys in height. The average building height for this region was 12m.The test area also includes several hills with terrain height variations in the order of 60 meters. The height of the antennas was set to 15m, 5m and 1.5m for BS, RN and MS respectively. Carrier frequencies of 2.1GHz and 5.2GHz were assumed.

For the study of the spatial shadowing auto-correlation, 6 moving routes were defined in Single Route simulation mode, during which the TX remained at a fixed location while the receiver (RX) moving around. The RX was set to be a MS, and the TX was set to be either a MS, RN or BS for comparison. As the spatial correlation is environment dependent, to obtain the averaged correlation function, 6 routes were placed at different areas on the map, with a total length of 8km. For the MS-MS link shadowing cross-correlation investigation, Route Set simulation mode was defined, in which route set was used. Each route set consists of a moving TX route as well as a moving RX route. 4 route sets have been defined in the city centre area, with a total length of 2km (TX) x 2km

(RX). The route configurations are shown in Figure 2. The channel data has been generated with RX (and TX in Route Set mode) moving along the pre-set routes at 1 metre intervals.

Figure 3 shows an example of the predicted local mean received power and the shadow fading from Single Route simulation mode. The Route Set mode result is shown in Figure 4. The term of local mean received power was obtained by summing the power in all the arriving rays, where the phase of each ray was not taken into account; hence the fast fading is averaged out. The shadowing data was calculated by subtracting the local mean power by the distance dependent mean path loss found in the previous study [12]. For more detailed information, please refer to [12].

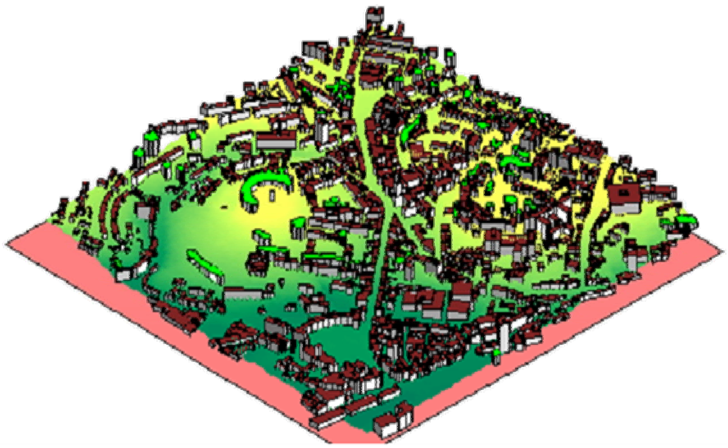
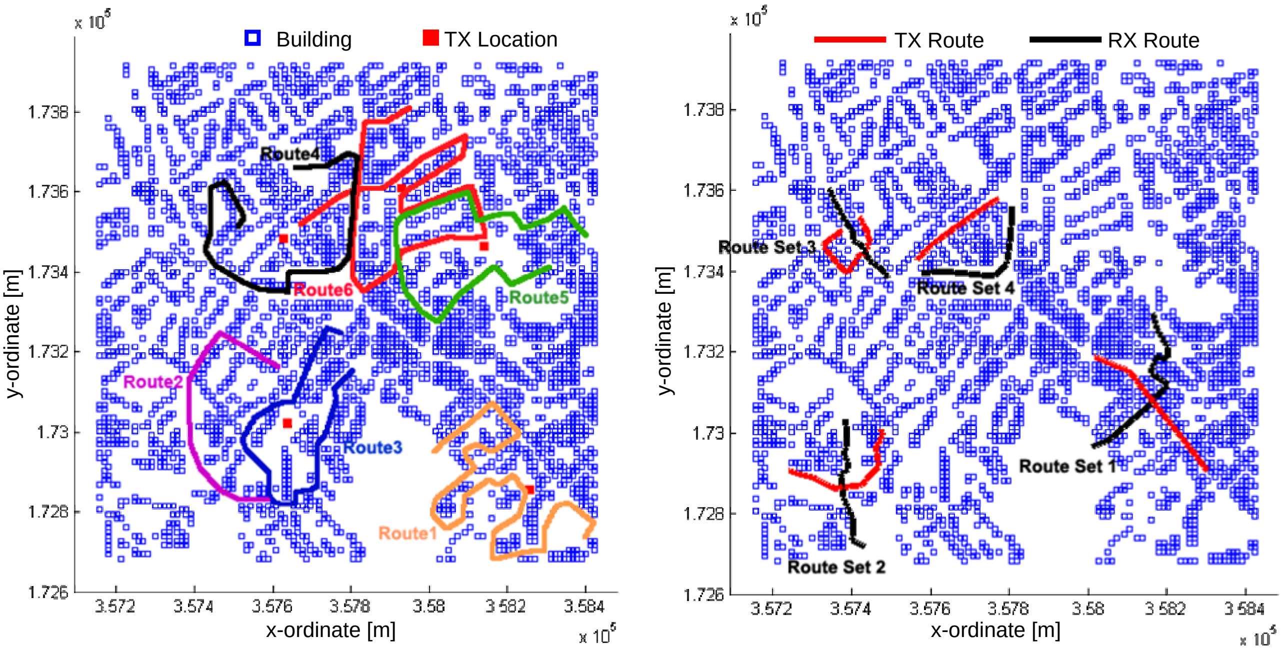
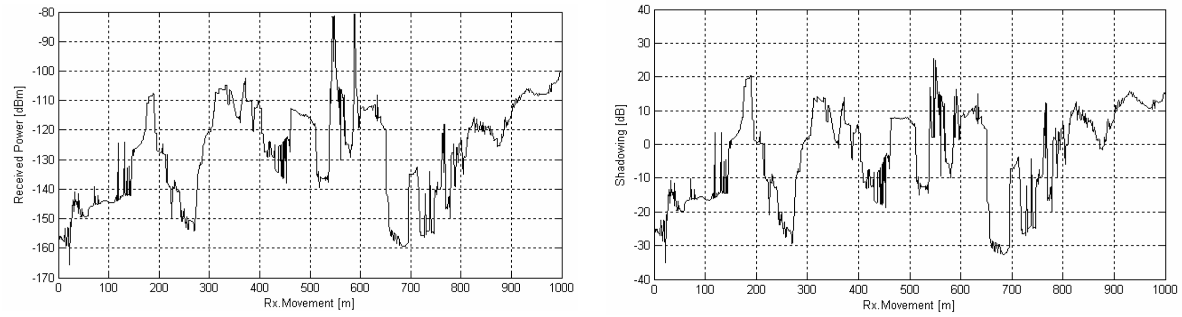


Figure 1: Bristol database as used in the simulations



(a) (b)

Figure 2: Routes Setting, (a) Single Route mode, (b)Route Set mode



(a) (b)

Figure 3: (a) The received power, and (b) shadowing data from simulation on route1

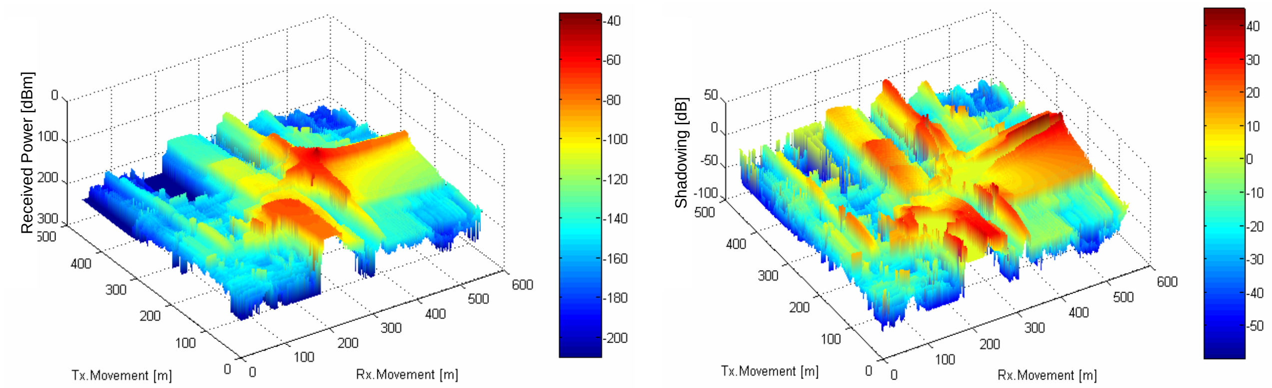


Figure 4: The received power (left) and shadowing (right) data from simulation on route set 1

III. Analysis of Shadowing Correlation

A. Spatial Autocorrelation Function

The spatial autocorrelation function of the shadow fading is a measure of how fast the local mean power evolves as the MS moves along a certain route. As discovered in a previous study [12], the shadowing variation is distance dependent. To fairly estimate the shadowing spatial correlation, instead of using the entire set of data in one route, in which the RX displacement is approximately 1.8km, the auto-correlation function is calculated every 200m along each route. The results from 6 different Single Route mode simulations are then averaged and plotted in Figure 5.

It is observed that the exponential decaying function accurately models the spatial autocorrelation function of the shadow fading, which is defined as:

$$R_1(\Delta d) = e^{-\frac{|\Delta d|}{d_{cor}}\ln 2} \qquad (1)$$

where Δd represents the movement of the RX, the de-correlation distance represented by d_{cor} , which is dependent on the environment, and corresponds to the distance at which the correlation drops to 50% correlation. For the city of Bristol in this stipulation, the best fit de-correlation distance d_{cor} was found to be 20m.

Furthermore, it can be seen in Figure 5 that the auto-correlation function for all kinds of link types are similar, despite the varying TX heights and operating frequencies. This is reasonable given that the shadowing fluctuation is due to the birth and death of multi-paths, which corresponds to the changing of the scatters around TX and RX. During the simulations, only the RX, i.e. the MS, is moving, and hence the shadowing fluctuations are mainly caused by changes in the surround buildings near to the MS.

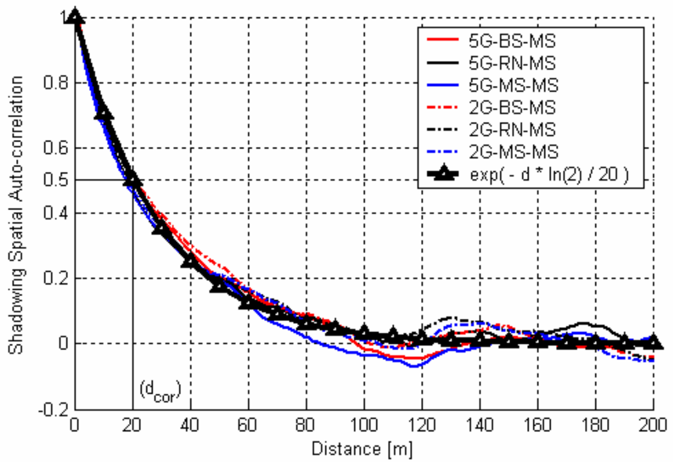


Figure 5: The shadowing spatial auto-correlation function (Averaged)

B. Joint Spatial Correlation Function

The shadowing joint spatial correlation function is a measure of how fast the local mean power evolves when the MSs, at both ends of a peer-to-peer radio link, move around, as illustrated in Figure 6. It is particularly important for shadowing process generation in the system level simulations for routing protocols and RRM algorithm performance evaluations in multihop/Ad-hoc networks. The joint-correlation function can be estimated by calculating the 2D auto-correlation function based on the results from Route Set mode simulations.

The averaged 2-D shadowing spatial auto-correlation function is shown in Figure 7, where the TX and RX movement distance shifts are limited to 100 meters. The correlation coefficient is between 0.1 and -0.1 when the distance shift is beyond 100m. Using $R_2\ (\Delta d_T, \Delta d_R)$ to represent the 2-D auto-correlation function, it has been discovered from Figure 7 that the following relationship exists:

$$R_2\ (\Delta d_T, \Delta d_R) = R_1\ (\Delta d_T) * R_1\ (\Delta d_R) \qquad (2)$$

where Δd_T and Δd_R denote the movement of the TX and RX respectively. $R_1\ (\Delta d)$ represents the one-dimensional auto-correlation function. Substituting from (1), we obtain:

$$R_2\ (\Delta d_T, \Delta d_R) = R_1\ (\Delta d_T + \Delta d_R) \qquad (3)$$

Equation (2) indicates that the 2-D shadowing spatial auto-correlation can be decomposed as the combination of two independent 1-D spatial auto-correlation functions, which correspond to the movements at each terminal respectively. One explanation for this relationship could be that the shadowing fluctuation is only a result of the changes of local scatters around the moving terminal, and so the movements of the terminals at both end of the link are uncorrelated. Under such conditions, equation (2) would be true.

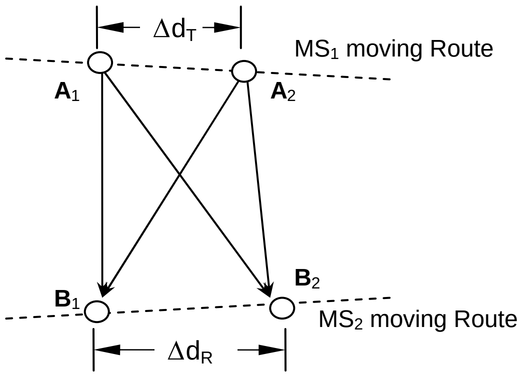
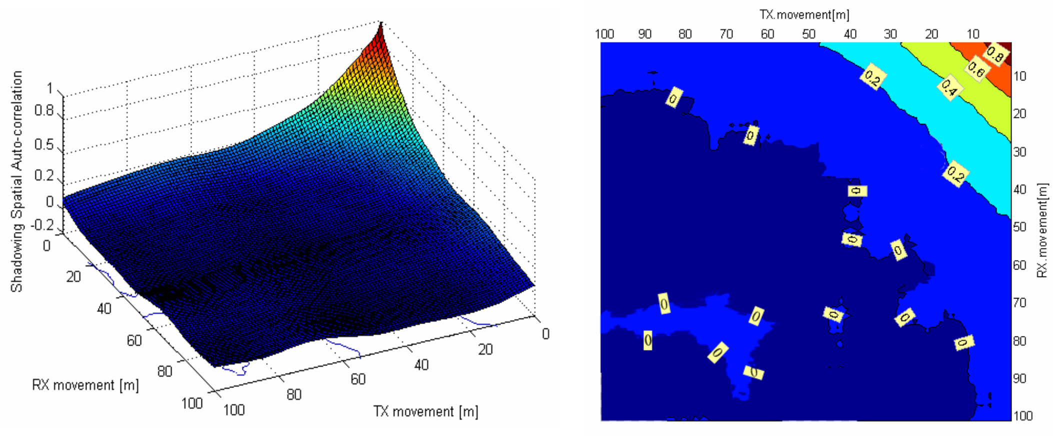


Figure 6: Peer-to-Peer link model



(a) 3D plot

(b) Contour plot

Figure 7: The shadowing spatial joint-correlation function for MS-MS links, 3D and Contour plot

IV. Shadowing Process Model

A number of computer simulation models have been proposed to simulate fading channels. One straight forward method is to firstly generate the shadowing values **n** for each link as statistically independent random variables, which are thus uncorrelated; and to then apply the correlation using a matrix **A**:

$$\boldsymbol{s} = \boldsymbol{A}\,\boldsymbol{n} \tag{4}$$

where $\boldsymbol{n}$ is an N dimensional column vector with elements that are statistically independent random variables, $\boldsymbol{A}$ is an NxN matrix and $\boldsymbol{s}$ is an N dimensional column vector which consists of the required shadowing values, with the correlation matrix $\boldsymbol{R} = \boldsymbol{A}\,\boldsymbol{A}^{H}$**.** Knowing that all the values are real numbers, it can be further simplified to $\boldsymbol{R} = \boldsymbol{A}\,\boldsymbol{A}^{T}$. Once $\boldsymbol{R}$ is determined by the correlation function $R_2(\Delta d_1, \Delta d_2)$, $\boldsymbol{A}$ can be resolved by Cholesky factorization. The shadowing model developed in [11] is a special case of this kind of model with the number of links limited to two.

However, the computational complexity of Cholesky factorization for an *NxN* matrix is $O(N^3)$, and for ad-hoc networks with *M* nodes, the number *N* of links is $O(M^2)$, Furthermore, to apply this model, the matrix ***A*** has to be positive definite to have a Cholesky factorization, which can not be guaranteed.

Instead of handling such 'big' matrix factorization, the shadowing process model we proposed in this paper is base on a filtering method. Basically, a stationary Gaussian process can be generated by passing a sequence of white Gaussian random deviates through a filter whose frequency response is the square root of the Gaussian process' power spectral density (PSD) [16, p. 403]. The PSD can be obtained by performing the Fourier transform on the autocorrelation function. Therefore, once the autocorrelation function is given, the filter that needed to generate the shadowing process can be calculated.

For the joint shadowing process, firstly a 4-D grid map with white Gaussian random variables is generated, which is denoted as $N(x_T,y_T,x_R,y_R)$. The first two dimensions in the 4-D map represent the TX location plane $d_T(x_T,y_T)$ on the virtual map, and the second two dimensions represents the RX location plane $d_R(x_R,y_R)$. This map is filtered by the filter calculated according to the autocorrelation function that extracted in the previous section. Let $\Phi_1(f)$ and $\Phi_2(f_T,f_R)$ represent the Fourier transform of the correlation function $R_1(d)$ and $R_2(d_T, d_R)$ respectively, recall that it has been found that the shadowing fluctuations caused by MS movements at each end of the link are independent, i.e. equation (2), we can obtain:

$$\phi_2(f_T,f_R)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}R_2(d_T,d_R)\cdot e^{-j(2\pi f_T\cdot d_T+2\pi f_R\cdot d_R)}d(d_T)d(d_R) \qquad (5)$$

$$\begin{aligned}
&=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}R_1(d_T)\cdot R_1(d_R)\cdot e^{-j\cdot 2\pi f_T\cdot d_T}e^{-j\cdot 2\pi f_R\cdot d_R}d(d_T)d(d_R)\\
&=\int_{-\infty}^{\infty}R_1(d_T)\cdot e^{-j\cdot 2\pi f_T\cdot d_T}d(d_T)\int_{-\infty}^{\infty}R_1(d_R)\cdot e^{-j\cdot 2\pi f_R\cdot d_R}d(d_R)\\
&=\phi_1(f_T)\cdot\phi_1(f_R)
\end{aligned}$$

where *f* and *d* are vectors and can be replaced with (f_x,f_y) and (d_x,d_y), hence equation (5) is actually a 4-D Fourier transform. Equation (5) indicates that the filter can be applied to the d_T and d_R dimensions separately, i.e. we only need the filter that corresponds to the traditional autocorrelation function $R_1(d)$, which has already been well studied [8]. After filtering, the shadowing value for the given TX and RX location on the virtual map can be interpolated according to the resulted grid shadowing map $u_S(x_T,y_T,x_R,y_R)$. The flow chart for generating the spatial correlated shadowing map is shown in Figure 8.

The motivation to use a 4-D map, which could be considered as a combination of two 2-D virtual planes, is to fulfil the needs in multihop/Ad-hoc network simulations. For example, a mobile may be moving along a closed route rather than a straight line, and we may want to study how the routing protocol and RRM algorithms perform. In this case, a 1-D shadowing process cannot be used because it cannot capture the correlation of the channel along this closed route.

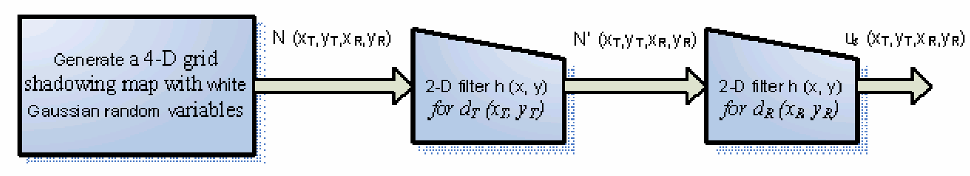


Figure 8: Flow chart for generating the spatially correlated shadowing map

For practical implementation, the channel shadowing is expected to be symmetrical, which means if we exchange the locations of TX and RX, the shadowing value should be the same, i.e. $u_S(x_T,y_T,x_R,y_R) = u_S(x_R,y_R,x_T,y_T)$. This requirement can be achieved by manually making the 4-D white Gaussian random matrix conform to reciprocity such that $N(x_T,y_T,x_R,y_R) \Leftrightarrow N(x_R,y_R,x_T,y_T)$. This, however, will introduce extra correlation between d_T and d_R dimensions when the separation between TX and RX is less than the de-correlation distance (20m). This limitation may prevent this model applying to network simulations with high subscribe density.

V. NUMERICAL RESULTS

In this section, we present numerical results from the proposed joint shadowing process model. We simulate the shadowing process for MS-MS links in the urban scenario, where we assume the autocorrelation function $R_1(\Delta d)$ is symmetric at all directions, i.e.:

$$R_1(\Delta x, \Delta y) = e^{-\frac{\sqrt{\Delta x^2+\Delta y^2}}{d_{cor}}\ln(2)} = e^{-\frac{|\Delta d|}{d_{cor}}\ln(2)} = R_1(\Delta d) \qquad (6)$$

The 2D auto-correlation function $R_1(\Delta x, \Delta y)$ and the corresponding filter $h(x,y)$ are shown in Figure 9. We generate a virtual map with size 500m x500m. The grid sampling distance was set to 10m and the filter size 200m x 200m. Figure 11 shows an example of the generated shadowing and the resulted 2D autocorrelation function. With the generated virtual map, 1-D autocorrelation and joint correlation are evaluated based on Single route and Route set modes with random TX and RX routes. The averaged results over 50 runs are shown in Figure 11. It can be seen that the proposed shadowing process model accurately regenerates the channel shadowing spatial property in term of correlation functions.

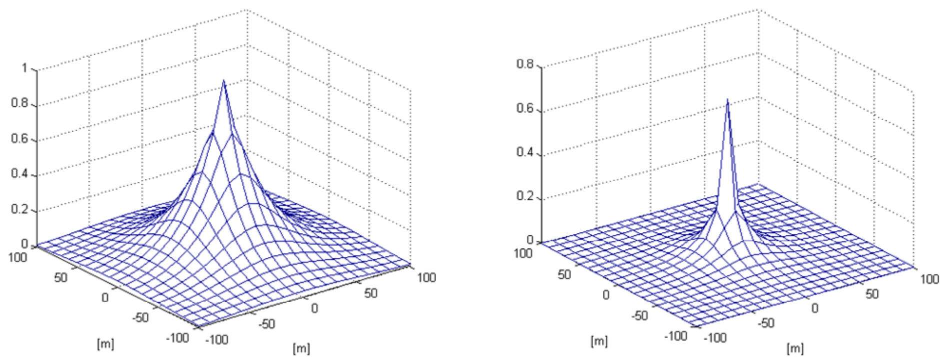


Figure 9: The 2D auto-correlation function $R_1(\Delta x, \Delta y)$ and the corresponding filter $h(x,y)$

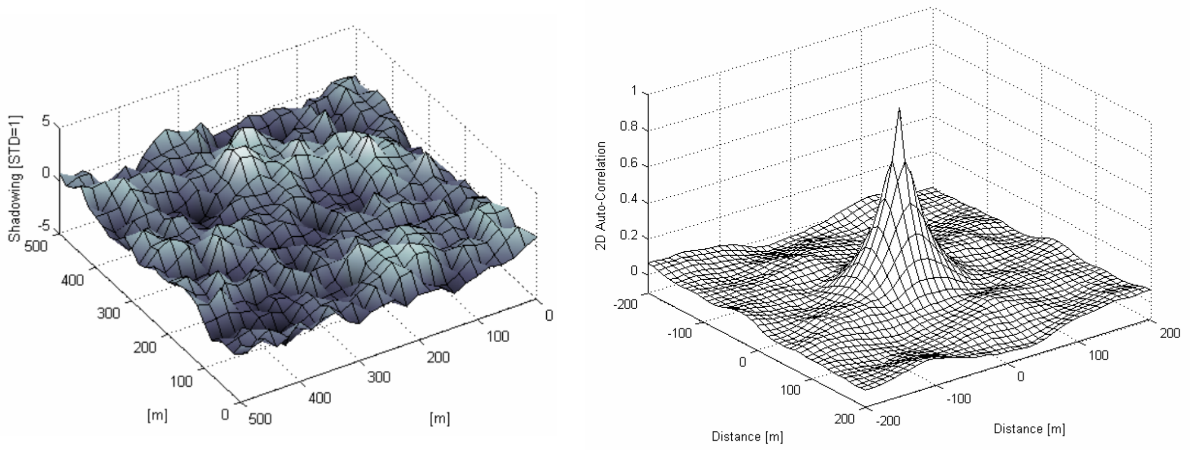


Figure 10: Example of generated shadowing plane (left), and the resulted 2D autocorrelation function (right)

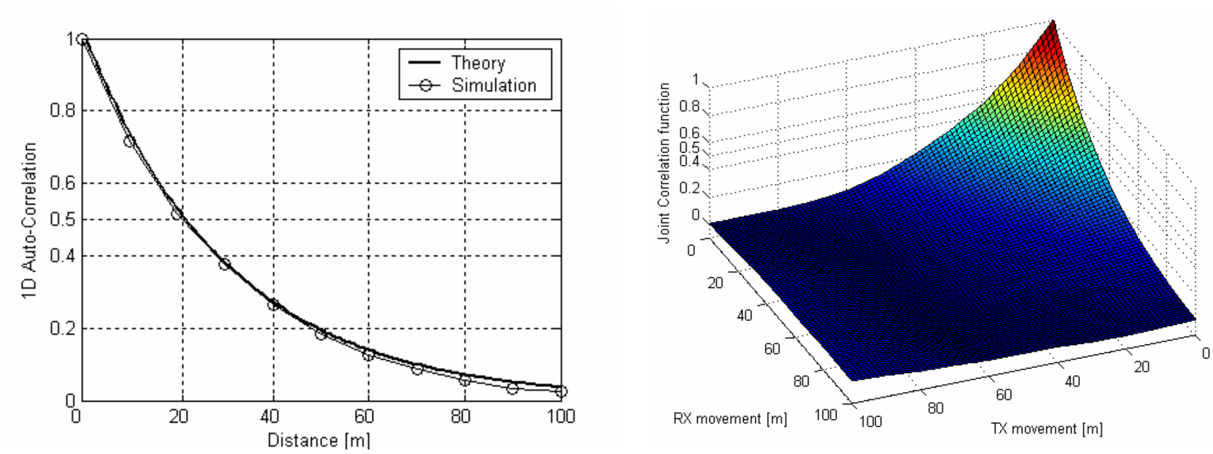


Figure 11: Averaged 1-D Autocorrelation function (left) and Joint correlation function (right) from the simulation

VI. Conclusion

In this paper, the spatial/temporal correlation of the shadowing property for peer-to-peer radio links in urban environments has been investigated and the joint correlation function extracted. A filtering based shadowing process model has been proposed. Simulations illustrate that this channel model provides the ability to generate a more realistic shadowing process in a M2M peer-to-peer channels in urban environments, which are particularly attractive for use in system level simulations that incorporate multihop/ad-hoc and fixed relay network elements in an urban environment.

Acknowledgment

The authors would like to thank the European Union IST-ROMANTIK Project for financial assistance.

References

[1] 3GPP TR 25.924 V1.0.0. 3GPP TSG-RAN, "*Opportunity Driven Multiple Access*", Dec. 1999.

[2] R. Ramanathan, J. Redi, "*A Brief Overview Of Ad Hoc Networks: Challenges And Directions*" IEEE Comm. Magazine, May, 2002

[3] J. Vidal, M. Madueño, J. R. Fonollosa, S. Barbarossa, O. Gasparini, S. Ponnekanti, A. Andritsou, A. Nix, "*Multihop networks for capacity and coverage enhancement in TDD/UTRAN*", MedHocNet 2002, Sardinia (Italy), September 2002.

[4] A. N. Zadeh et al, *"Self-Organising Packet Radio Ad hoc Networks with Overlay (SOPRANO)",* IEEE Communications Magazine, June, 2002.

[5] M. Lott et al, "*Medium Access and Radio Resource Management for Ad Hoc Networks based on UTRATDD*", MobileHOC,2001.

[6] "*Digital Mobile Radio Towards Future Generation Systems*", COST 231 Final Report, Chapter2, 4, 1998

[7] L. M. Correia, "*Wireless flexible personalized communications, COST 259: European co-operation in mobile radio research*" ISBN 0471 49836X, pp.77-222, 2001

[8] Xiaodong Cai, Member, IEEE, and Georgios B. Giannak, *A Two-Dimensional Channel Simulation Model for Shadowing Processes,* IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 52, NO. 6, NOVEMBER 2003

[9] H. Kim, Y. Han, "*Enhanced Correlated Shadowing Generation in Channel Simulation*", IEEE COMMUNICATIONS LETTERS, VOL. 6, NO. 7, JULY 2002

[10] N. Patwari, Y. Wang, and R. J. O'Dea, "*The importance of the multipointto -multipoint indoor radio channel in ad hoc networks,*" in IEEE Wireless Commun. and Networking Conf., (Orlando, FL), pp. 608--612, Mar. 2002

[11] Fabio Graziosi, Fortunato Santucci, *A General Correlation Model for Shadow Fading in Mobile Radio Systems* IEEE COMMUNICATIONS LETTERS, VOL. 6, NO. 3, MARCH 2002

[12] Z Wang, E. K. Tameh, A. R. Nix, *"Statistical Peer-to-Peer Channel Models for Outdoor Urban Environment at 2GHz and 5GHz"*, submitted to IEEE VTC,F04

[13] E K Tameh, A.R. Nix, " *A 3-D integrated macro and microcellular propagation model, based on the use of photogrammetric terrain and building data*", IEEE VTC'97 Proceedings, Vol. 3, pg. 1957-1961

[14] E K Tameh, A.R. Nix, "*The Use of Measurement Data to Analyse the Performance of Rooftop Diffraction and Foliage Loss Algorithms in a 3-D Integrated Urban/Rural Propagation Model.*", IEEE VTC'98

[15] E K Tameh "*The development and evaluation of a deterministic mixed cell propagation model based on radar cross-section theory*", PhD Thesis, 1998

[16] A. Papoulis, "*Probability, Random Variables, and Stochastic Processes*". New York: McGraw-Hill, 1991.