Correlation Characteristics of 2-Dimensional Antenna Array Signals in a Multi-Cell Environment

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***Abstract*—In this paper, we analyze the 3-dimension spatial channel model (3D-SCM) over time and spatial domains. SCM is a realistic channel model for multiple-input multiple-output (MIMO) wireless communication systems since it is known to adequately represent the channel properties with respect to the antenna geometry and conditions of user equipments (UEs). We observe its autocorrelation properties over time and spatial domains as functions of the angle spread and the effective Doppler frequency. The results can be used for efficient design of transmission methods, such as beamforming and precoding using codebooks to fully utilize the channel characterstics of two-dimensional antenna arrays.**

Keywords—**Correlation; MIMO; 2D Arrays; SCM; Angle spread; Doppler frequency.**

I. Introduction

To further increase the bandwidth efficiency of mobile wireless systems, MIMO systems which use multiple antenna elements are being utilized in LTE Release 8 and later releases [1]. It is expected that the number of antenna elements will keep increasing for even higher data rates and bandwidth efficiency. Thus it is important that we understand channel characteristics for different arrangements of antenna elements [2]. 3D-SCM is a channel model for MIMO transmission adopted by the 3GPP Spatial Channel Ad-hoc Group. The model contains a set of parameters, verification methods, and the minimum requirements. It is based on the ray-tracing method and probability models for geometric environments. Various parameters are defined for each of transmission scenarios [3]-[5]. Although these standardization documents specify the setup, implementation procedures, and key characteristics of resulting channels, related studies on how to utilize these results to efficiently design the transmission schemes are not currently well known. More recently, enhancements using full-dimensional MIMO have been discussed and related issues are summarized in [6]. Channel state information reference signaling (CSI-RS) and its enhancement schemes are published as 3GPP meeting documents [7],[8].

In this work, we analyze the 3D-SCM which is implemented by the simulation tool to represent the correlation properties over time and spatial domains. In time domain, we observe autocorrelation of channels for different effective Doppler frequencies of UEs based on their mobility and directions. We compare the autocorrelation of SCM to that generated by the Jake's channel model which follows the zeroth order Bessel function. In spatial domain, we observe the correlation for vertical and horizontal antenna elements respectively, with respect to antenna spacing. We utilize the angle spread to represent the measure of how much beam separation among antenna elements exist [9].

The rest of the paper is organized as follows. In Section II, system model and parameters used for the channel characteristic evaluation are described. Specific results on correlation behavior of the channel model are given in Section III, followed by discussion and conclusions in Section IV.

II. System Model and Parameters

The system model with 19 cells for which each sector has a hexagonal coverage is used, and UEs are assumed to be uniformly distributed in each sector. Each base station (BS) has 16 antenna elements made up of 4 vertical and 4 horizontal antenna arrays, whereas each UE has a single antenna element. Detailed steps of generating 3D-SCM and system parameters used for simulation are similar to those described in [5]. First, environments and parameters are given for UMa (Urban Macro) model, and indoor/outdoor distribution ratio is set as 80 to 20%. Second, departure/arrival angles as well as the pathloss values are determined. Third, delay and power profiles for each cluster are calculated, followed by random coupling among subpaths in each cluster. The fourth step is the assignment of phase values and crosspol factors. Finally, channel coefficients are computed for SCM.

Jakes' channel model is generated for comparison purposes using the Doppler frequency f_d determined as $f_d = v/\lambda$ where v is the UE mobility and λ is the signal wavelength [10]. The zeroth order Bessel function $J_0(\cdot)$ is used for the autocorrelation function (ACF), written as $R[n] = J_0(2\pi f_d T|n|)$ for the time domain [11]. The ACF for the spatial domain can be similarly described as $R[m_H] = J_0(2\pi\delta_H|m_H|d_H/\lambda)$ and $R[m_V] = J_0(2\pi\delta_V|m_V|d_V/\lambda)$ where m_H, m_V are antenna element indices, δ_H, δ_V are angle spreads, and d_H, d_V are antenna spacing. Subscripts H and V represent the horizontal array and vertical array, respectively. We define also κ as $\kappa_H = \delta_H d_H/\lambda$ and $\kappa_V = \delta_V d_V/\lambda$. Doppler frequency value

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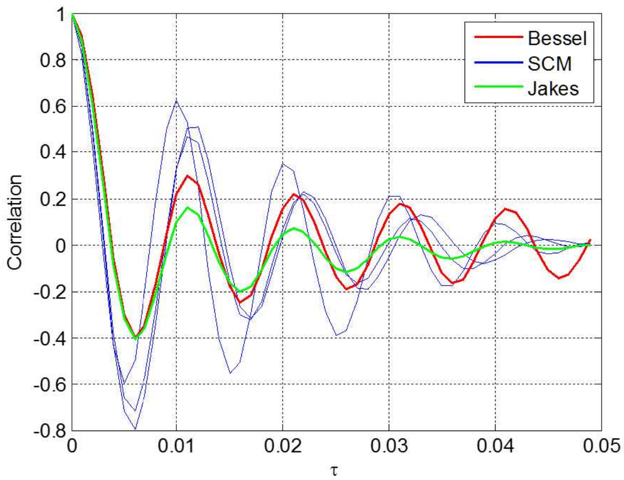

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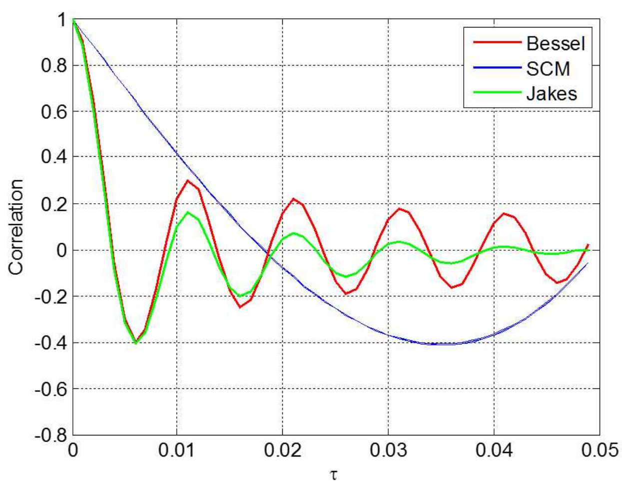

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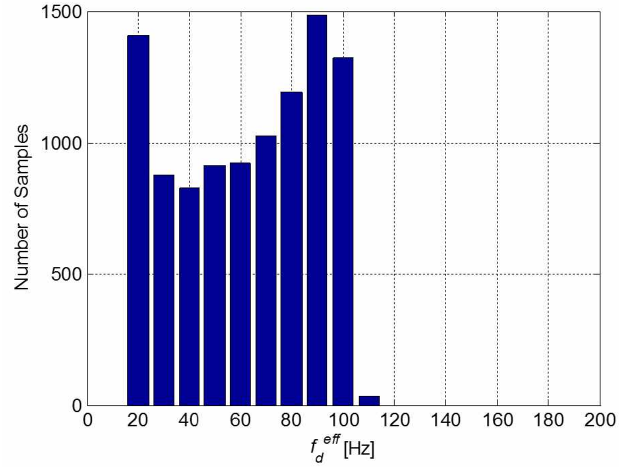
Figure 1. Comparison of ACFs: (a) $\phi_v = 0^o$ and (b) $\phi_v = 90^o$.



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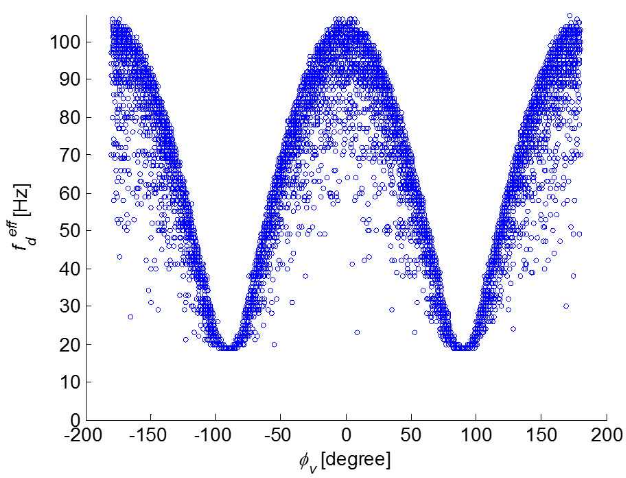

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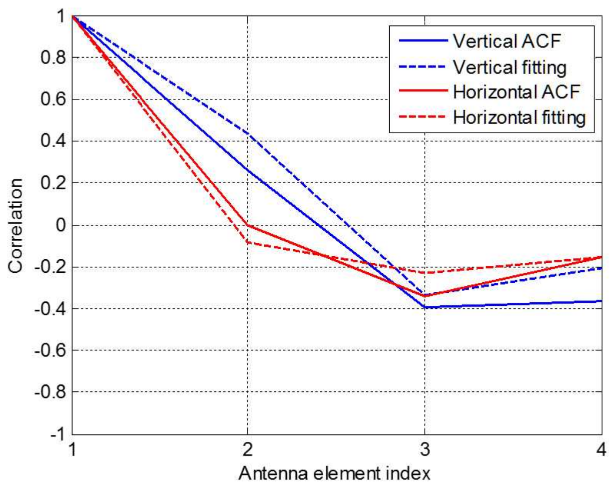
Figure 2. Distributions for the effective Doppler frequency: (a) Histogram and (b) f_d^{eff} versus ϕ_{LOS}.

of $f_d = 100$Hz is used for simulation. Effective Doppler frequency is determined as $f_d^{eff} = v \cos\phi_v/\lambda$ which considers the UEs' direction angle ϕ_v. Also, κ^{eff} represents the effective angle spread of each UE.

III. Correlation Characteristics

The ACFs as functions of time difference τ are shown in Figure 1. The autocorrelation values were observed by the Monte-Carlo simulation; Channel coefficients are repeatedly generated in random locations within the sector at different time instances, then correlation values at different time intervals are measured by taking the average of those correlation values. Angles $\phi_v = 0^o$ and 90^o represent different moving directions of UEs, which are respectively the same as and perpendicular to the antenna boresight. For UEs with $\phi_v = 0^o$, AFCs are in good agreement to the existing Bessel function model. On the other hand, the UEs with $\phi_v = 90^o$ have high correlation for small time difference values. The distribution of f_d^{eff} and f_d^{eff} versus ϕ_v are summarized in Figure 2.

To verify the ACF characteristics of spatial domain, we first observe the autocorrelation of UEs with respect to vertical and horizontal antenna elements. Then we determine κ_V^{eff} and κ_H^{eff} by the curve fitting method, considering four vertical and horizontal antenna elements for cases of $d_H = d_V = 0.5\lambda$ and $d_H = d_V = 2\lambda$. The purpose of these observations is (1) to verify the accuracy of the curve fitting for horizontal and vertical AFCs, (2) to present the amount of correlation as the spacing between antenna element increases, and (3) to compare the correlation behavior of horizontal and vertical arrays, to better understand the statistical characteristics of SCM. The observation results for these two cases are given in Figures 3 and 4, respectively. Simulations and figure drawings have been produced by Matlab software. The ACFs evaluated in Figure 1 shows that the SCM model implemented produces a reasonable autocorrelation properties needed to simulate the mobile users, as can be seen from the comparison to results produced using the Bessel function and Jakes' fading



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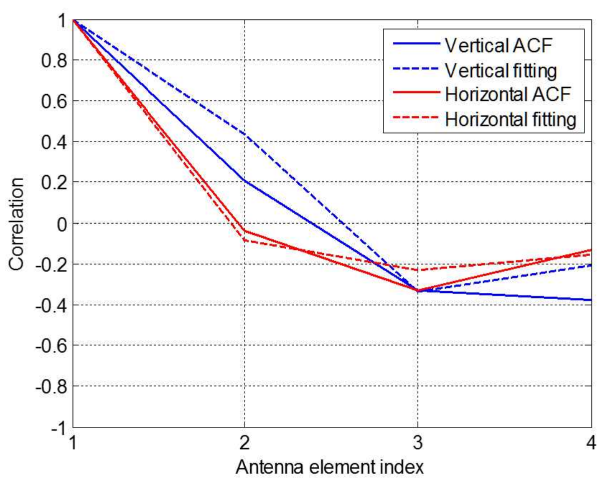

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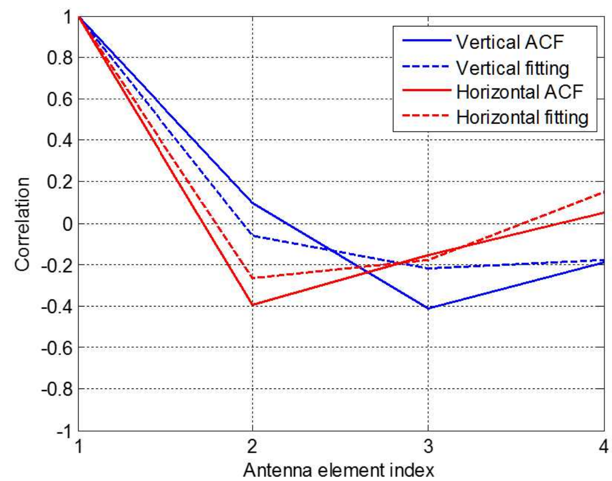
Figure 3. Actual ACF and curve fitting result for $d_H = d_V = 0.5\lambda$: (a) Specific location and (b) the sector average.



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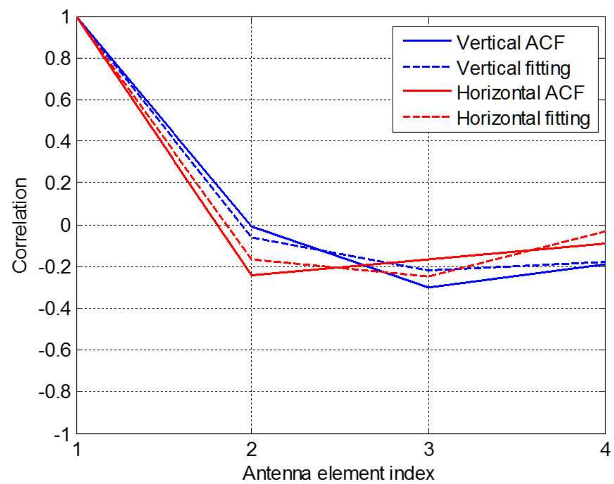

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Figure 4. Actual ACF and curve fitting result for $d_H = d_V = 2.0\lambda$: (a) Specific location and (b) the sector average.

generation [12],[13]. For the users randomly located over the sector, the distribution for the effective Doppler frequency and the angle-dependent values are given in Figure 2. These results provide a guidance as to which Doppler values to be used for transceiver signal processing.

IV. Discussion and Conclusion

We implemented the 3D-SCM as a realistic correlated channel for MIMO transmission, and analyzed it in both time and spatial domains. We observed the autocorrelation characteristics by experimental results and compared them to existing models. We also determined the effective Doppler frequency in time domain and the effective angle spread in spatial domain by curve fitting. Even when the Doppler frequency of UEs are the same, the autocorrelation function are not the same due to the multipath effects of UEs moving in different directions. By using the distribution results for the effective angle spreads of UEs vertically and horizontally, we observe that the effective angle spreads are mainly dependent on antenna spacing. We can utilize the statistical results of this work for several different purposes of designing the MIMO transmission strategies. For example, theses can be used for channel interpolation, as well as the channel prediction in both domains when only partial knowledge of the actual channel is given. The results can also be applied in selecting beam-forming strategies for the multi-antenna system. Distributions of the channel can be exploited in designing appropriate codebooks to be used in precoding the transmission signal. The estimated Doppler frequency can be used to obtain the precoding vectors in subsequent transmission frames when the exact and full channel information is not present at those frames, by performing extrapolation of previous channel report results.

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