A NEW COST-EFFECTIVE MISO/SIMO CHANNEL MODEL FOR MACRO-CELLULAR SYSTEM SIMULATIONS

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ABSTRACT

In this paper, we propose a new very cost-effective channel model for MISO/SIMO macro-cellular simulations. The channel model is very light computationally, especially when the mobile changes angular position. It uses a finite impulse response (FIR) with time-varying coefficients for each antenna, and introduces spatial correlation between the antenna elements, with a slight difference in the correlation properties compared to Jakes' model, by considering every path as made of a finite number of subpaths. The channel model and the correlation properties are detailed, and the simulation results are presented and discussed.

I. INTRODUCTION

With the growth of the wireless communications networks, the operators found themselves constrained to achieve higher spectrum efficiency. Adaptive antennas are seen as some of the most promising technologies to do so.
Abundant, is the literature that evaluates the capacity improvement by the use of multiple antennas [1], [2]. Most of the works require, however, heavy computer simulations to measure the link and system-level performance. In the special case of multiple antennas, a channel model incorporating special spatiotemporal characteristics is required for such purposes.
The articles [3] and [4] suggested models that are based on the decomposition of the channel into time-differentiable paths (TDP) which are composed of multiple time-nondifferentiable subpaths (TNS). The time correlation properties were consequences of the geometric architecture of the propagation environment. As an alternative to the latter constraints, [5] presented a model that include inherently the time correlation properties. That simulator uses an eigen-decomposition and needs numerical integrations to induce proper spatial correlation between antenna elements. The inconvenient is that those computationally heavy steps should be recalled each time the mobile changes its angular position making the complexity of the channel building process considerable.
In this paper, we present a new cost-effective channel model for MISO/SIMO macro-cellular simulations. It is computationally light for the case of a mobile changing angular position during the simulations, because, neither eigen-decomposition, nor numerical integrations are required during the process. Our approach uses a finite impulse response (FIR) with time-varying coefficients for each antenna, and introduces spatial correlation between the antenna elements, with a slight difference compared to the Jakes' model, by considering every path as made of a finite number of subpaths.

The structure of the paper is as follows. In section 2, our new channel model is introduced. Then the temporal properties of the model are viewed in section 3, before analyzing the spatial properties in section 4. Section 5, shows some simulation results related to the topic. Conclusions are finally presented in section 6.

II. CHANNEL MODEL

A. Assumptions

In our model, we make the following assumptions:

- All over the paper, we consider the downlink. Extension to the uplink is straightforward.
- The mobile has a single isotropic antenna surrounded by uniformly distributed scatterers [6]. Meanwhile, the base station is located high enough, not to be shadowed by local scatterers (e.g. on a tower).
- The base station and the mobile are far enough from one another as to create a near planar wavefront over the antenna array surface.
- The radio channel is composed of multiple paths, continuously distributed in time (delay of arrival), but associated with a finite number of discrete angles of departure, in contrast to [5] which supposes a continuous distribution of subpaths in time (delays) and space. This assumption allows a significant reduction of the computation complexity when the mobile's angular position is time-varying with respect to the antenna array.
- Traveling through different directions, rays of the same path are independent.
- The sub-paths are distributed following a law which divides the total path energy amongst them. Many distributions of rays such as uniform, truncated laplacian and gaussian were proposed [7]. In our approach, we use finite discrete distributions.

B. Channel Construction

Our vision of the channel structure is illustrated in figure 1. Without any loss of generality, we assume the p^{th} time differentiable path seen by the a^{th} antenna as being composed of an odd number of rays with discrete angles of departure according to the discrete power distribution f_k. The channel

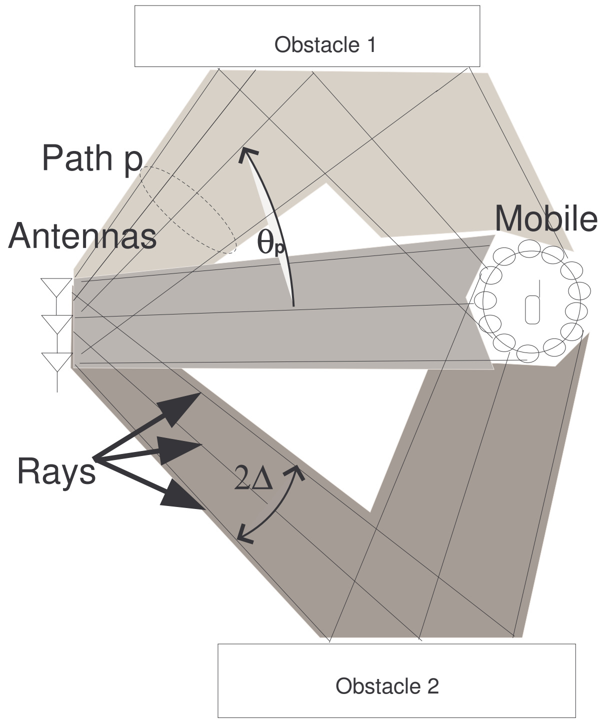

Fig. 1. Channel structure.

tap can be written in that case:

$$c_{p,a}(n) = \varepsilon_p \sum_{k=-K}^{K} \sqrt{f_k} r_k(n) \exp\Bigg(- j2\pi\frac{d}{\lambda}(a-1) \times \sin(\theta_p(n) + k\frac{\Delta}{K})\Bigg) \quad (1)$$

where $2K+1$ is the number of rays considered in every path. $r_k(n)$ is the Rayleigh fading coefficient for the k^{th} ray at time n. The term ε_p is the fraction of the total channel energy granted to the p^{th} path. λ is the wavelength, and d is the spacing between two antenna elements of a uniform array. $\theta_p(n)$ denotes the path angle from the broadside of the antenna array. 2Δ refers to the maximal angular opening, which determines the angular range where a path is truncated.

III. TEMPORAL CORRELATION

We compute the temporal correlation of the channel coefficient as follows:

$$R_{c_{p,a}c_{p,a}}(n, n+m) = \mathbf{E}[c_{p,a}(n+m)c^*_{p,a}(n)] \quad (2)$$

where $\mathbf{E}$ refers to the expectation, $R_{c_{p,a}c_{p,a}}$ is the correlation between the channel tap at time n and time $n+m$. Using equation (1), we have:

$$\begin{aligned} R_{c_{p,a}c_{p,a}}(n, n+m) &= \varepsilon_p^2 \sum_{k=-K}^{K}\sum_{i=-K}^{K} \mathbf{E}[r_i(n+m)r_k^*(n)] \\ &\times \sqrt{f_k}\sqrt{f_i}\exp\Bigg(j2\pi\frac{d}{\lambda}(a-1)\sin\Big(\theta_p(n)+k\frac{\Delta}{K}\Big)\Bigg) \\ &\times \exp\Bigg(-j2\pi\frac{d}{\lambda}(a-1)\sin\Big(\theta_p(n+m)+i\frac{\Delta}{K}\Big)\Bigg). \end{aligned} \quad (3)$$

Since the ray coefficients $r_k(n)$ are subject to a Rayleigh fading with a normalized Doppler spread frequency f_d , we can write:

$$\mathbf{E}[r_i(n+m)r_k^*(n)] = \delta_{i,k}J_0(2\pi f_d m) \quad (4)$$

where J_0 is the 0^{th} order Bessel function. From the equation above, we have:

$$\begin{aligned} R_{c_{p,a}c_{p,a}}(n, n+m) &= \varepsilon_p^2 \textstyle\sum_{k=-K}^{K} J_0(2\pi f_d m) f_k \\ &\times \exp\Bigg(j2\pi\tfrac{d}{\lambda}(a-1)(\sin(\theta_{p,k}(n)) \\ &- \sin(\theta_{p,k}(n+m)))\Bigg) \end{aligned} \quad (5)$$

where

$$\theta_{p,k}(n) = \theta_p(n) + k\frac{\Delta}{K}. \quad (6)$$

Using trigonometric identities, we can rewrite equation (5) in the following form:

$$\begin{aligned} R_{c_{p,a}c_{p,a}}(n, n+m) &= \varepsilon_p^2 \sum_{k=-K}^{K} J_0(2\pi f_d m) f_k \\ &\times \exp\Bigg(j4\pi\frac{d}{\lambda}(a-1)\cos\Big(\frac{\theta_{p,k}(n)+\theta_{p,k}(n+m)}{2}\Big) \\ &\times \sin\Big(\frac{\theta_{p,k}(n)-\theta_{p,k}(n+m)}{2}\Big)\Bigg) \end{aligned} \quad (7)$$

By substituting (6) in (7), we obtain

$$\begin{aligned} R_{c_{p,a}c_{p,a}}(n, n+m) &= \varepsilon_p^2 J_0(2\pi f_d m) \sum_{k=-K}^{K} f_k \\ &\times \exp\Bigg(j4\pi\frac{d}{\lambda}(a-1)\cos\Big(\frac{\theta_p(n)+\theta_p(n+m)}{2}+k\frac{\Delta}{K}\Big) \\ &\times \sin\Big(\frac{\theta_p(n)-\theta_p(n+m)}{2}\Big)\Bigg). \end{aligned} \quad (8)$$

If we consider the case where the angle θ_p varies in time with a constant angular speed ω_p, i.e.

$$\theta_p(n) = \omega_p n + \theta_0, \quad (9)$$

then (8) becomes:

$$\begin{aligned} R_{c_{p,a}c_{p,a}}(n, n+m) &= \varepsilon_p^2 J_0(2\pi f_d m) \sum_{k=-K}^{K} f_k \\ &\times \exp\Bigg(j4\pi\frac{d}{\lambda}(a-1)\cos\Big(\frac{2\omega_p n+\omega_p m+2\theta_0}{2}+k\frac{\Delta}{K}\Big) \\ &\times \sin\Big(-\frac{\omega_p m}{2}\Big)\Bigg). \end{aligned} \quad (10)$$

The resulting expression of (10) keeps a very close shape to the 0^{th} order bessel function given by the classical Jakes' propagation model [6], except some negligible deviations that can be seen in our model due to the effect of the angular speed. The difference between the two expressions reduces with the decrease of the angular speed.

IV. SPATIAL CORRELATION

Let us compute the correlation coefficient between the a_1^{th} and the a_2^{th} antenna channel taps on the same path p. If we consider two random variables X and Y of mean μ_X, μ_Y and of standard deviation σ_X and σ_Y respectively. By definition, we can write the correlation coefficient ρ_{XY} as:

$$\rho_{XY} = \frac{\mathbf{E}[(X-\mu_X)(Y^*-\mu_Y^*)]}{\sigma_X \sigma_Y}. \tag{11}$$

In our case we know that both variables of interest are zero mean. So let us calculate the upper part of the definition of ρ which is the correlation between the variables at time n. It is given by:

$$\mathbf{E}[c_{p.a_1}(n)c^*_{p.a_2}(n)] = \varepsilon_p^2 \sum_{k=-K}^{K} \sum_{i=-K}^{K} \mathbf{E}[r_i(n)r_k^*(n)] \times \sqrt{f_k}\sqrt{f_i} \exp\left\{ -j2\pi\frac{d}{\lambda}(a_1-1)\sin\left(\theta_p(n)+k\frac{\Delta}{K}\right)\right\} \times \exp\left\{ j2\pi\frac{d}{\lambda}(a_2-1)\sin\left(\theta_p(n)+i\frac{\Delta}{K}\right)\right\},$$

which can be simplified due to the fading independence amongst rays, to become:

$$\mathbf{E}[c_{p.a_1}(n)c^*_{p.a_2}(n)] = \varepsilon_p^2 \sum_{k=-K}^{K} f_k \times \exp\left\{ -j2\pi\frac{d}{\lambda}(a_1-a_2)\sin\left(\theta_p(n)+k\frac{\Delta}{K}\right)\right\}. \tag{12}$$

This equation yields a standard deviation of ε_p for both variables by setting $a_2 = a_1$. Finally we can write the correlation coefficient as:

$$\rho_{c_{p.a_1}c_{p.a_2}}(n) = \sum_{k=-K}^{K} f_k \exp\left\{ -j2\pi\frac{d}{\lambda}(a_1-a_2) \times \sin\left(\theta_p(n)+k\frac{\Delta}{K}\right)\right\}. \tag{13}$$

From equation (13), we can write the envelope correlation as:

$$\rho^e_{c_{p.a_1}c_{p.a_2}}(n) = |\rho_{c_{p.a_1}c_{p.a_2}}(n)|^2 = \left| \sum_{k=-K}^{K} f_k \exp\left\{ -j2\pi\frac{d}{\lambda}(a_1-a_2) \times \sin\left(\theta_p(n)+k\frac{\Delta}{K}\right)\right\}\right|^2. \tag{14}$$

Note that, as expected, the correlation coefficients depend on the time-varying angular position $\theta_p(n)$.

V. SIMULATIONS

In our new approach, we used a finite discrete distribution instead of a continuous time distribution. In the following, we consider a discrete laplacian one (see the appendix). Besides, we consider the path p, and use the following parameters unless specified otherwise.

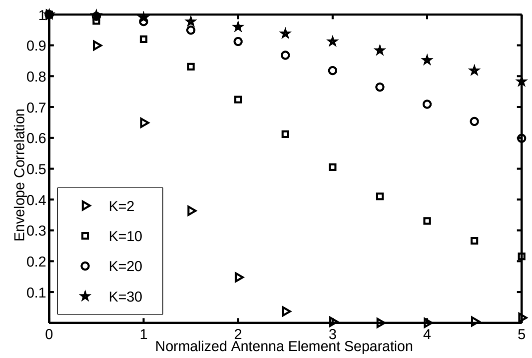

Fig. 2. Effect of K on the spatial correlation coefficient.

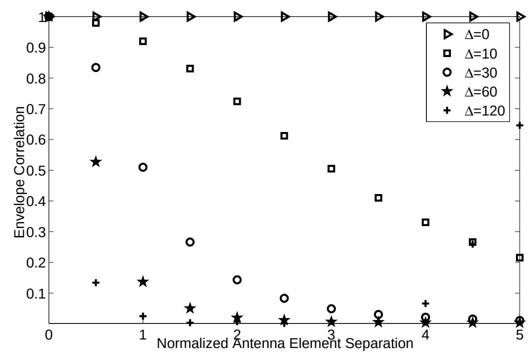

Fig. 3. variation of spatial correlation coefficient with respect to Δ in degrees and d/λ for $\theta_p = 0^o$.

parameter	value
K	10
σ	2.82 (or $\sigma_d = 2.65$ for $K = 10$)
Δ	10^o
Speed	60km/h
Frequency	5GHz
Antenna separation	$\frac{\lambda}{2}$
ω	10^{-4}rad/s

In figure 2, we plot the effect of the parameter K on the spatial correlation coefficient, for a constant σ_d and Δ.

It is clear that with a fixed σ_d, the higher the value of K is, the more spatially correlated are the channels.

Figures 3 and 4 plot the variation of the spatial correlation versus the normalized antenna separation for different values of maximal angular opening and for two values of mean angle of departure $\theta_p = 0$ and $\theta_p = 70$.

From figures 3 and 4, we can observe, that when the mobile's angle of departure approaches the endfire angular position, the correlation increases. And, for low antenna element separation, the higher the maximal angular opening is, the lower the correlation will be.

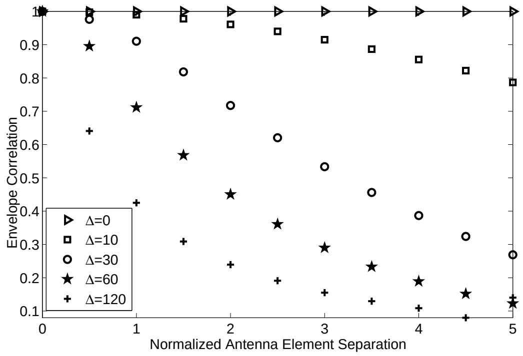

Fig. 4. variation of spatial correlation coefficient with respect to Δ in degrees and d/λ for $\theta_p = 70^o$.

VI. CONCLUSION

In this article, we have presented a new cost-effective channel model for MISO/SIMO macro-cellular system simulations for a mobile with time-varying angular position. We have proven that our model induces spatial correlation between channel taps without loss of the temporal correlation properties which remain the same as the one given by Jakes' model.
Furthermore, our approach has a very low computation cost, since neither eigen-decomposition nor numerical integrations are involved in the channel building process.

APPENDIX

A. Discrete Laplacian Distribution

In the continuous time case, the laplacian distribution is defined as :

$$f(x) = \frac{1}{2\alpha}\exp(-\frac{x}{\alpha}), \qquad \forall x \in \mathbf{R}. \tag{15}$$

The parameter α is linked to the standard deviation σ of the distribution by:

$$\sigma = \sqrt{2}\alpha. \tag{16}$$

To be used in our model, this distribution should be first truncated, then discretized (a limited number of rays), and finally normalized which gives a distribution with a general term:

$$f_k = \frac{1-e^{-\frac{1}{\alpha}}}{1-2e^{-\frac{K+1}{\alpha}}+e^{-\frac{1}{\alpha}}}e^{-\frac{|k|}{\alpha}}, \quad \forall k \in \{-K,\cdots,0,\cdots,K\}. \tag{17}$$

After calculations, the new discrete law standard deviation σ_d is:

$$\sigma_d = \left(\frac{2z}{(1+z-2z^{K+1})(1-2z+z^2)} \times \left[1+z - (K+1)^2 z^K + (2K^2+2K-1)z^{K+1} - K^2 z^{K+2}\right]\right)^{\frac{1}{2}} \tag{18}$$

where by definition $z = e^{-\frac{1}{\alpha}} = e^{-\frac{\sqrt{2}}{\sigma}}$. Figure 5 illustrates an example of the distribution. The angular spread in this case is

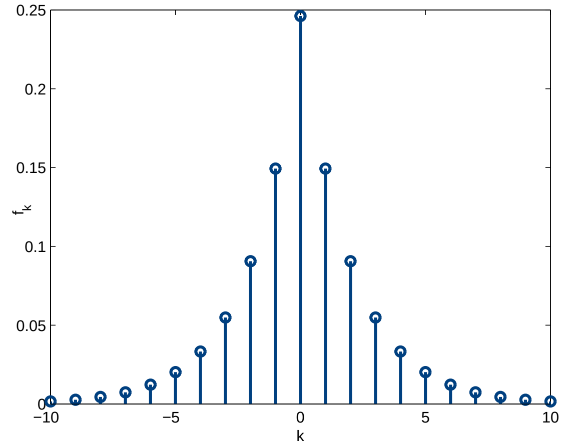

Fig. 5. Discrete laplacian distribution.

given by

$$\sigma_\theta = \frac{\sigma_d \Delta}{K}. \tag{19}$$

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