The Effect of Mobile Station Rotation on a Correlation Model for Microcellular Environments

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Abstract— **This paper studies the effect of rotation of a Mobile Station (MS) on the Cross-Correlation Function (CCF) derived for a microcellular isotropic wave propagation environment with enough number of scatterers. The statistical model characterizes the propagation media when the MS rotates with a constant angular velocity around an axis perpendicular to the azimuthal plane, and moves with a constant velocity on the azimuthal plane in an arbitrary direction. The moving MS with a constant speed produces the conventional linear Doppler while the rotating MS introduces angular Doppler. The research shows that the rotation of the MS results in a non-stationary random process as the CCF. The only exception in which the result follows a stationary function is a narrow-band communication system, when either the MS angular velocity or the MS speed is zero.**

Keywords: Wireless channel modeling, Cross-Correlation model, MS rotation, linear Doppler, angular Doppler.

I. Introduction

Fast growing demand for high data-rate wireless communication using wireless systems, the limited available bandwidth, as well as the widespread usage of these systems in different locations, motivates the investigation of more effective, more flexible, and more realistic wireless systems. In order to propose an efficient design of such a system, communication engineers seek for any reliable resource of information about the propagation environment. A wireless channel may be dependent on several parameters including: frequency; time; receiver/transmitter translation; receiver orientation; Transmitter Orientation; multi-element receiver, and multi-element transmitter [1]. Transmitter or receiver orientation/rotation which turns out to be important in certain situations, is an almost neglected issue in the context of wireless channel modeling. This variation is because of movements of the mobile user in the propagation environment [2].

The Channel Impulse Response (CIR) varies with rotation of Mobile Station (MS) or Base Station (BS). A moving MS with rotational motion affects the channel model in two different ways: *linear Doppler* caused by its straight motion, and *angular Doppler* caused by its rotation around an axis. There are not many fundamental works in the literature to investigate the effect of this rotation on the channel model. The work proposed by Pakravan, Kavehrad, and Hashemi [3], [4] suggests an experimental framework to study the effect of rotation in wireless channels. These researchers report on a set of measurements to investigate the effect of rotation on the parameters of indoor infrared channels. More specifically, they create a large data base of channel frequency response to study the effect of receiver rotation on the channel path-loss and its delay spread. They show that the delay spread of the channel and its path-loss are linearly correlated on the log scale when the station is rotated. They elaborate the measurement set up and procedures in [3], and present the results in [4].

In this paper and under some simplifying assumptions, we study the effect of rotation of the MS on the Cross-Correlation Function (CCF) of a wireless radio channel. We consider a microcellular environment with enough number of scatterers on both sides of MS and BS [5], [6]. Wave propagation is assumed to be planar in the two-dimensional (2D) azimuthal plane. Many related physical parameters, such as phase change in the received waveform; time-delay; channel-gain as a function of the time-delay; Direction of Arrival (DOA); and Direction of Departure (DOD) are considered. The BS is fixed in the plane, while the MS moves with a constant speed on the azimuth plane and rotates with a constant angular velocity around the azimuthal axis. The proposed model describes statistical characteristics of a 2D Rayleigh channel with a rotating MS as a function of space, time, and frequency. As this research talks about the conditional CCF in condition of a certain and simple movement/rotation, its result is useful when we have some statistical information on how a MS[1] moves/rotates on the plane [2]. In other words, the result of this research is easily used as a basic element to characterize the CCF of a wireless channel considering the MS movements.

The rest of this paper is organized as follows: The notations and the assumptions are presented in Section II considering the MS rotation (see [5], [6] for more details). The new Space-Time-Frequency CCF considering the MS rotation is derived in Section III. Some discussions and simulation results on the behavior of the model are proposed in Section IV. The behavior of the correlation model in the presence of MS rotation is described in the results section. Finally conclusions are drawn in Section V.

II. Physical Assumptions

Figure 1 shows BS-MS antennas in a 2D propagation environment. The superscript B indicates variables at the BS

[1] A MS is usually a human as a user of the cellular service. Therefore, we need statistical models on the free human movements [2].

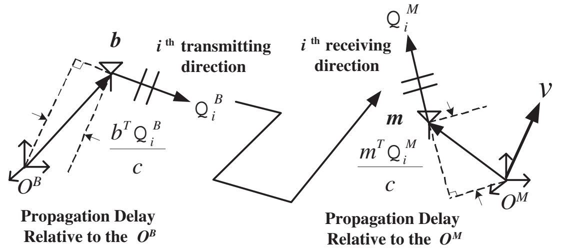


Fig. 1. **General Propagation Scenario from BS to MS:** BS antenna and MS antenna in their local coordinates. Time delay of i^{th} propagating waveform to the MS has three components: two relative propagation delays, and one major distance delay.

and the superscript M is used for variables on the MS side. The subscript i indicates variables related to the i^{th} dominant path. The following notations are used in this paper:

O^B	BS coordinate,
O^M	MS coordinate,
$h(t,\omega)$	CIR between BS and MS;
$\mathbf{b}$	Position of BS antenna relative to O^B;
$\mathbf{m}$	Position of MS antenna relative to O^M;
$\boldsymbol{\Theta}_i^B$	The unity vector pointing to DOD from BS;
$\boldsymbol{\Theta}_i^M$	The unity vector pointing to DOA from MS;
$\mathbf{v}$	MS speed vector;
ω	Carrier frequency;
c	Wave propagation velocity;
I	Number of total dominant paths;
$\tau_{B,M;i}$	Delay between BS and MS antenna elements;
$g_{B,M;i}$	Gain between BS and MS antenna elements, approximated by g_i;
ϕ_i	Phase contribution along the i^{th} dominant path;
θ	Softness factor;
ϖ_i	Shifted frequency by the Doppler phenomenon;
κ	Correlation coefficient between sub-channels,
β_i	Fast fading factor;
η	Pathloss exponent;
σ	Variance of the time-delay τ_i;
$\overline{\tau}$	Mean of the time-delay τ_i; and,
ν	MS angular velocity.

We assume that the position of the MS antenna element does not change with time relative to the MS coordinate, while the coordinate itself moves in a constant linear speed of $\mathbf{v}$ and rotates in a constant angular velocity of ν. In Figure 1 the position of antennas at MS and BS are arbitrarily selected with respect to their local coordinates. The antennas are assumed to be omnidirectional. Each antenna receives the signal through the media via a large number of propagating paths with uniform DODs and DOAs, since the MS and the BS are assumed to have almost the same height [1]. Overall, the propagation media is considered to be a rich scattering microcellular environment [8], [9]. Notations Θ_i^B and Θ_i^M represent DOD and DOA unity vectors of the i^{th} path at BS and MS respectively (see Figure 1). Vector $\mathbf{v}$ represents the MS mobility on a horizontal plane. Figure 2 shows the schematic of the rotation of the MS around an axis perpendicular to the azimuthal plane. The rotation is

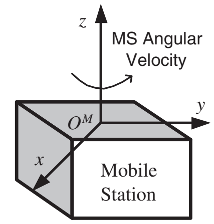


Fig. 2. **MS in Presence of Rotation Around the Azimuthal Axis:** Two-dimensional wave propagation scenario with a rotating MS around the azimuthal axis. The MS rotates with a fixed angular velocity, ν.

considered to be in a constant angular velocity.

The model used in this paper is based on some assumptions of physical parameters which are explained here [5], [6]:

A1) The azimuthal angles are all uniformly distribution over $[-\pi,\pi)$, i.e, $\angle\boldsymbol{\Theta}_i^B$ and $\angle\boldsymbol{\Theta}_i^M \sim U[-\pi,\pi)$. In other words, the environment is an isotropic scattering media.

A2) The i^{th} propagation delay, $\tau_{B,M;i}$, is decomposed as:

$$\tau_{B,M;i} = \tau_i - (\tau_i^B + \tau_i^M), \quad (1a)$$

$$\tau_i^B \triangleq \frac{B^T\Theta_i^B}{c}, \quad (1b)$$

$$\tau_i^M \triangleq \frac{M^T\Theta_i^M}{c}, \quad (1c)$$

where τ_i represents delay between O^B and O^M, and τ_i^B and τ_i^M represent relative delays from antenna elements, $\mathbf{b}$ or $\mathbf{m}$. We assume that τ_i's are independent identically distributed (i.i.d.) with pdf $\tau_i \sim \frac{1}{\sigma}e^{-\frac{\tau-\overline{\tau}+\sigma}{\sigma}}$, $\forall\tau \geqslant \overline{\tau}-\sigma$, where $\overline{\tau}$ is the average time-delay related to the propagation distance and σ is the variance of delay. Moment Generating Function (MGF) of τ_i is $\boldsymbol{\Phi}_\tau(s) = \frac{e^{(\overline{\tau}-\sigma)s}}{1-\sigma s}$.

A3) Figure 2 shows the schematic of a rotating MS in the horizontal 2D plane. This rotation introduces another source of channel variation in Space Time (ST) channel modeling [1]. In a rotational MS scenario, vector indicating the location of MS antenna, $\mathbf{m}(t)$, is time-varying. This position vector has two parts including a fixed component and a time-varying component

$$\mathbf{m}(t) = \mathbf{m}_0 e^{j\nu t}, \quad (2)$$

where $\mathbf{m}_0$ is the initial position vector. From (1) and (2), and considering the fact that we are characterizing a microcellular isotropic wave propagation environment, it turns out the impact of this rotation mainly appears on the delay profile at the MS side in the form of a time-varying propagation delay. In fact, because in an isotropic environment the rotation of the MS (BS) makes no change in the angular spread seen by the station, the only effect will be on the delay of the wave traveling toward (from) the station. This time-varying propagation delay for the i^{th} path in the MS side is written as:

$$\tau_i^M(t) = \frac{\mathbf{m}^T(t)\boldsymbol{\Theta}_i^M}{c}. \quad (3)$$

A4) Path gain, $g_{B,M;i}$, and propagation delay, $\tau_{B,M;i}$, are random parameters that are both functions of path length; therefore, they are dependent. When $|\tau_i| \gg \max\left\{|\tau^B_{p;i}|, |\tau^M_{m;i}|\right\}$, the following relation has been used to describe this interaction [8]:

$$g_{B,M;i} \simeq g_i = \beta_i \left(\frac{\overline{\tau}}{\tau_i}\right)^{\frac{\eta}{2}} \sqrt{P_0}. \quad (4)$$

where β_i is the fast fading factor [8], η is called pathloss exponent, and P_0 is a constant. The fast fading factor is assumed to be a stationary time-invariant random process, independent of the time-delay, $\tau_{p,m;i}$. We also assume that $E[\beta_i^2] = 1$ and $E[\beta_{i_1}\beta_{i_2}] = \kappa$, where $0 \leqslant \kappa < 1$ is the correlation coefficient [8]. Depending on the propagation media, the pathloss exponent is usually measured between 2 and 6 [8].

A5) The phase contribution of scatterers are considered by a random phase change, ϕ_i, as: $p_{\boldsymbol{\phi}}(\phi) \sim U[0, 2\theta]$; $0 \leqslant \theta < \pi$, and θ is the softness factor. The random phase change, ϕ_i, is independent from channel gain, time-delay, and fast fading factor, β_i.

III. Model Description

A solution basis for Maxwell's equations is to break down the received waveform into a linear combination of an appropriate set of elementary functions [1], e.g., the set of plane waves [1], [9]. Planar waves emitted from the antenna $\mathbf{b}$ travel over several propagation paths with different lengths. We assume that the waves are scattered in the propagation media and reach the MS $\mathbf{m}$ via a number of dominant paths from different directions. The following expression describes the CIR of such a propagation scenario [5], [6],

$$h(t,\omega) = \frac{1}{\sqrt{I}} \sum_{i=1}^{I} g_{B,M;i} \exp\left(j\phi_i + j\varpi_i t - j\omega\tau_{B,M;i}\right), \quad (5)$$

where I is the number of dominant paths resulting from scattering, and $g_{B,M;i}/\sqrt{I}$ is the real gain, a function of the time-delay and the fast fading factor [8]. The frequency of i^{th} waveform is denoted by $\varpi_i \triangleq \frac{\omega}{c}\mathbf{v}^T\boldsymbol{\Theta}_i^M$, where ω is the carrier frequency and $\mathbf{v}^T\boldsymbol{\Theta}_i^M/c$ is the Doppler spread factor.

We derive a closed-form expression for the ST cross-correlation function between CIRs of two arbitrary communication links, $h(t_1,\omega_1)$ and $h(t_2,\omega_2)$. This correlation function is denoted by [5], [6],

$$R(t_1,t_2;\omega_1,\omega_2) \triangleq E[h(t_1,\omega_1)\; h^*(t_2,\omega_2)]. \quad (6)$$

Replacing (1), (3), (4), and (5) in (6), considering the characteristics of a planar wave [1], [5], using Assumptions A1-A5 established in this section, and doing some manipulations, $R(t_1,t_2;\omega_1,\omega_2)$ is decomposed as follows:

$$\frac{P_0\overline{\tau}^\eta}{I} \sum_{i_1,i_2=1}^{I} \left\{E[\beta_{i_1}\beta_{i_2}] E\left[(\tau_{i_1}\tau_{i_2})^{\frac{-\eta}{2}} e^{j\left(\omega_2\tau_{i_2} - \omega_1\tau_{i_1}\right)}\right] \quad (7)$$
$$\times \quad E\left[\exp(j(\phi_{i_1} - \phi_{i_2}))\right]\right\} J_0(|\mathbf{d}^B|) J_0(|\mathbf{d}^M|),$$

where,

$$\mathbf{d}^B \triangleq \frac{\omega_1 - \omega_2}{c}\mathbf{b},$$
$$\mathbf{d}^M \triangleq \frac{\omega_1 t_1 - \omega_2 t_2}{c}\mathbf{v} + \left(\frac{\omega_1}{c}e^{j\nu t_1} - \frac{\omega_2}{c}e^{j\nu t_2}\right)\mathbf{m}_0,$$

$J_0(z) \triangleq \frac{1}{2\pi}\int_0^{2\pi} e^{jz\cos u} du$, and the amplitude of a vector is denoted by $|.|$. Parameters $\mathbf{d}^B$ and $\mathbf{d}^M$ represent shifted distance vectors at BS and MS, respectively. Greater $\mathbf{d}^B$ and $\mathbf{d}^M$ often result in less ST correlation because of the form of the Bessel function. These parameters contain spatial, temporal, and frequency separation between $h(t_1,\omega_1)$ and $h(t_2,\omega_2)$. As it is seen, effect of rotation appears as a sinusoidal time-varying component in the operand of the Bessel function. Also by looking at the obtained result, even in a narrow-band communication, i.e., $\omega_1 = \omega_2$, the proposed CCF depends on different time indices, t_1 and t_2. This means that the suggested model in presence of MS rotation offers a non-stationary random process to characterize the wireless channel. More specifically, the proposed model introduces a stationary random process just in the case that in a fixed carrier frequencies either the MS angular velocity, ν, or the MS speed, $\mathbf{v}$, is zero. It means that the model presents a stationary random process in a narrowband communication system when the MS movement is either purely linear or purely angular.

Considering expectations in (7), using Assumption 4, MGF of the i.i.d. time-delays[2], MGF of i.i.d. phase changes[3], and doing some manipulations, we get $R(t_1,t_2;\omega_1,\omega_2)$ as [5], [6]

$$P_0\overline{\tau}^\eta\; J_0(|\mathbf{d}^B|)J_0(|\mathbf{d}^M|)\; \boldsymbol{\Phi}_\tau^{(\eta)}\left(j(\omega_2 - \omega_1)\right) + \quad (8)$$
$$+\; P_0\overline{\tau}^\eta \left(\frac{\sin\theta}{\theta}\right)^2 J_0(|\mathbf{d}^B|)J_0(|\mathbf{d}^M|) \times$$
$$\times (I-1)\kappa \left(\boldsymbol{\Phi}_\tau^{(\frac{\eta}{2})}(-j\omega_1)\boldsymbol{\Phi}_\tau^{(\frac{\eta}{2})}(j\omega_2)\right),$$

where $\boldsymbol{\Phi}_\tau^{(\eta)}(s)$ is obtained by $(\eta)^{\text{th}}$-times integration of the time-delay MGF, $\boldsymbol{\Phi}_\tau(s)$. We assume that $\frac{\eta}{2}$ is a positive integer number [4]. The effect of slow fading is taken into account in the log-normal component by Assumption A4 [9], while β_i is assumed to be time-invariant [8], [9].

IV. Numerical Results and Discussions

In all our numerical results, the unit for the antenna spacing is half of the carrier wavelength, $\frac{\lambda}{2} \triangleq \frac{c\pi}{\omega}$. In what follows,

[2]Using Assumption A2, we have

$$E\left[(\tau_{i_1}\tau_{i_2})^{\frac{-\eta}{2}} \exp\left(j\left(\omega_2\tau_{i_2} - \omega_1\tau_{i_1}\right)\right)\right] =$$
$$= \begin{cases} \boldsymbol{\Phi}_\tau^{(\eta/2)}(j\omega_2)\,\boldsymbol{\Phi}_\tau^{(\eta/2)}(-j\omega_1), & i_1 \neq i_2, \\ \boldsymbol{\Phi}_\tau^{(\eta)}\left(j(\omega_2 - \omega_1)\right), & i_1 = i_2. \end{cases}$$

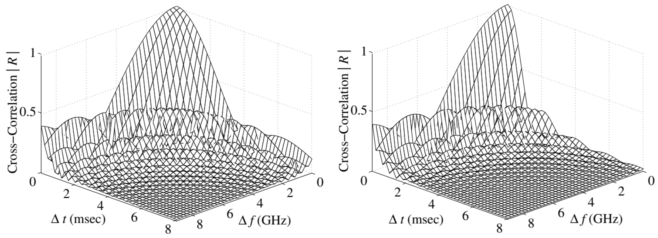
where $\boldsymbol{\Phi}_\tau(s) = \frac{e^{(\overline{\tau}-\sigma)s}}{1-\sigma s}$ is the MGF of the time-delay, τ_i.

[3]Using Assumption A5, we have

$$E\left[e^{j(\phi_{i_1} - \phi_{i_2})}\right] = \begin{cases} 1 & i_1 = i_2, \\ \boldsymbol{\Phi}_{\phi_{i_1}}(j)\boldsymbol{\Phi}_{\phi_{i_2}}(-j) & i_1 \neq i_2, \end{cases}$$

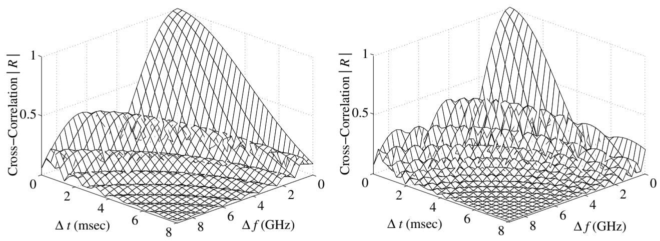
where $\boldsymbol{\Phi}_{\phi_i}(s) = \frac{e^{s\theta} - e^{-s\theta}}{2s\theta}$ is the MGF of the phase change, ϕ_i.

[4]The appropriate values for the pathloss is $\eta = 2$ for free propagation environments, $\eta = 4$ for rural environments, and $\eta = 6$ for crowded urban environments [8], [9].



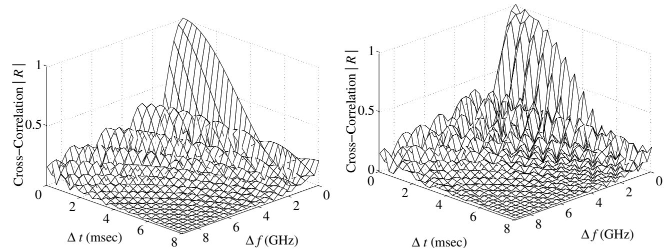
(a) $f_1 = 1$GHz (b) $f_1 = 3$GHz

Fig. 3. **Effect of Carrier Frequency:** CCF with respect to frequency offsets $\Delta f \triangleq f_2 - f_1$, for different time differences $\Delta t \triangleq t_2 - t_1$, $t_1 = 0$, the mobile speed, $\mathbf{v} = 40[1\ 0]^T$Km/h, the mobile angular velocity, $\nu = \frac{\pi}{4}$rad/sec, $\mathbf{m} = [1\ j]^T$cm, $\mathbf{b} = [0\ 0]^T$cm: a) $f_1 = 1$GHz, b) $f_1 = 3$GHz.



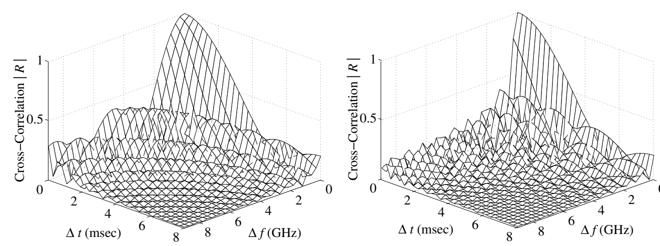
(a) $\mathbf{v} = 30[1\ 0]^T$Km/h (b) $\mathbf{v} = 60[1\ 0]^T$Km/h

Fig. 4. **Effect of MS Speed:** CCF with respect to frequency offsets $\Delta f \triangleq f_2 - f_1$, $f_1 = 1$GHz, for different time differences $\Delta t \triangleq t_2 - t_1$, $t_1 = 1$msec, the mobile angular velocity, $\nu = \frac{\pi}{4}$rad/sec, $\mathbf{m} = [1\ j]^T$cm, $\mathbf{b} = [0\ 0]^T$cm: a) $\mathbf{v} = 30[1\ 0]^T$Km/h, b) $\mathbf{v} = 60[1\ 0]^T$Km/h.



(a) $\nu = \frac{\pi}{4}$rad/sec (b) $\nu = \frac{\pi}{8}$rad/sec

Fig. 5. **Effect of MS Angular Velocity:** CCF with respect to frequency offsets $\Delta f \triangleq f_2 - f_1$, $f_1 = 1$GHz, for different time differences $\Delta t \triangleq t_2 - t_1$, $t_1 = 2$msec, the mobile speed, $\mathbf{v} = 40$Km/h, $\mathbf{m} = [1\ j]^T$cm, $\mathbf{b} = [0\ 0]^T$cm: a) $\nu = \frac{\pi}{4}$rad/sec, b) $\nu = \frac{\pi}{8}$rad/sec.



(a) $t_1 = 1$msec (b) $t_1 = 5$msec

Fig. 6. **Non-Stationary Behavior:** CCF with respect to frequency offsets $\Delta f \triangleq f_2 - f_1$, $f_1 = 1$GHz, for different time differences $\Delta t \triangleq t_2 - t_1$, the mobile speed, $\mathbf{v} = 40$Km/h, the mobile angular velocity $\nu = \frac{\pi}{4}$rad/sec, $\mathbf{m} = [1\ j]^T$cm, $\mathbf{b} = [0\ 0]^T$cm: a) $t_1 = 1$msec, b) $t_1 = 5$msec.

we use the Exponential distribution for the time-delay with a constant mean, $\overline{\tau} = 2\mu$sec, and variance, $\sigma = 100p$sec [8]. This profile is selected for a free space propagation environment when $\eta = 2$.

In Figure 3 normalized CCF, $\frac{R(t_1,t_2;\omega_1,\omega_2)}{R(t_1,t_1;\omega_1,\omega_1)}$, is plotted as a function of the carrier frequency offsets $\Delta f \triangleq f_2 - f_1$, and time differences $\Delta t \triangleq t_2 - t_1$, where $\omega_i = 2\pi f_i$ and f_1 is constant either at 1GHz or at 3GHz. This figure shows that the correlation decreases as the difference of either carrier frequencies Δf or time indices Δt increases. This decreasing property results from the Bessel functions and the other term caused by delay profile MGF.

Figure 4 shows joint Spatial-Frequency selectivity (i.e., the CCF is depicted as a function of $\Delta t = t_2 - t_1$ and $\Delta f = f_2 - f_1$) when the MS has different speeds $\mathbf{v}$. In this figure $t_1 = 1$msec and $f_1 = 1$GHz are fixed. Comparing Figures 4a and 4b, we observe that the mobile speed affects the CCF to a great extent; the CCF decreases significantly when the mobile speed increases. Figure 5 also shows the Spatial-Frequency selectivity comparing different mobile angular velocity ν. Comparing Figures 5a and 5b, we observe that the CCF not only decreases by the increase of the mobile angular velocity, but also its shape changes. In other words, depending on ν, the oscillations of the Bessel function gets effect of the $e^{j\nu t}$ term inside the operand of the Bessel function.

Non-stationary behavior of this model is an important attribute which is shown in our numerical results. Figure 6 shows this characteristic of the CCF in presence of the MS rotation. In this figure, the Temporal-Frequency selectivity of the model is examined under different conditions when the first time index t_1 is changing. Comparing Figures 6a and 6b, we observe that the shape of the CCF changes when we change the first time index t_1. This implies that the model does not depend on the time difference $t_1 - t_2$; therefore, it does not introduce a stationary random process. This discussion is valid for a wideband communication system when carrier frequencies f_1 and f_2 are different and far apart from each other. In the particular case when we consider a narrowband communication system, i.e., $f_1 = f_2$, the CCF may still represent a non-stationary random process. In other words, the model in general is not a function of the time difference $t_1 - t_2$ (see equation (7)). When the angular velocity of the MS is negligible in comparison to the mobile speed or vice versa (i.e., when the MS has either angular or linear movement in the azimuthal plane), this model proposes a stationary random process for narrowband communications. This feature is important when we use this model for simulation purposes.

We are interested in studying the effect of the new source of channel variations, the MS rotation, on the CCF. Figure 7 compares the CCF in two different scenarios: with and without rotation of MS. This comparison is accomplished with respect to different physical parameters which have key functions in the evaluation process. In order to see the effect of rotation in a better way, we choose a small value for the mobile speed. The figure shows that rotation has effect on both the amplitude and the period of oscillations of the correlation function.

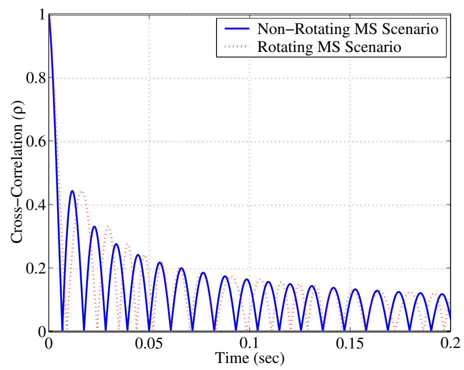


Fig. 7. **Comparison between Non-Rotating and Rotating MS scenarios:** The CCF with respect to second time index; first time index, $t_1 = 0$ sec; fixed carrier frequencies, $f_1 = 1$GHz, $f_2 = 2$GHz; mobile speed $\mathbf{v} = 10[1\ 0]^T$Km/h; angular velocity $\nu = \frac{\pi}{4}$rad/sec; fixed antenna positions, $\mathbf{m} = 2[1\ j]^T$cm, $\mathbf{b} = [1\ j]^T$cm; Solid: Non-Rotating MS, Dashed: Rotating MS.

Here, we raise an important discussion on the diameter and physical dimensions of the antenna element at MS, as well as the propagation pattern of this antenna. Looking at $\mathbf{d}^M = \frac{\omega_1 t_1 - \omega_2 t_2}{c}\mathbf{v} + \left(\frac{\omega_1}{c}e^{j\nu t_1} - \frac{\omega_2}{c}e^{j\nu t_2}\right)\mathbf{m}_0$ in (7), this equation shows that the rotation has no effect when the MS antenna is located at the origin of the MS coordinate. This is true when the antenna has no diameter ($\mathbf{m}_0 = 0$), the antenna has no special pattern, and the DOA is uniform. If any of these conditions is changed, then the rotation has a considerable effect on the CCF. In this paper, as it is mentioned before, we have considered uniform isotropic DOAs for incoming propagation paths to the MS and omnidirectional antenna elements with no special patterns [10]. In any case, if we break any of these assumptions, e.g., a non-isotropic propagation environment for incoming waves (non-uniform DOAs) [7], or directive antennas at MS which has special pattern in special directions [10], the effect of rotation is more considerable. In this situation, the mathematical model for the correlation function will be different from our equations. We are extensively dealing with some important cases considering different propagation conditions as well as different types of antennas in some of our future publications.

At the end of this section, we address different effects of rotation on the CCF to give a better picture on the meaning of the angular Doppler. As it is mentioned before, the rotation of the mobile station can cause different effects: 1. It changes the propagation delay of the incoming path into the antenna element, 2. It changes the angular spread of the incoming paths, seen by the MS. This scenario happens only the propagation environment is non-isotropic scattering [7]. The first effect causes some changes in the frequency (and the amplitude) of the received waveform, as it is seen in Figure 7. In harmony to its linear counterpart, this phenomenon is referred as the *angular Doppler* in this paper. The second effect which is not less important, is the change of the effective angular spread of the propagating waves. In a non-isotropic environment, the rotation produces an extra exponential term in the CCF, which is multiplied into the existing components [7]. In reality, the rotation of a user is not in the form of a pure rotation; therefore, statistical information on the rotational/orienatational movements of the MS/user is necessary to provide the precise form of the CCF [2].

V. Conclusions

We propose a very simple, closed-form and tractable expression for the CCF of an isotropic wireless propagation media with a rotating MS. More specifically, we model characteristics of a microcellular rich scattering environment when the MS moves with a constant velocity on the azimuthal plane in an arbitrary direction, and rotates with a constant angular velocity around an axis perpendicular to the azimuthal plane. The proposed model suggests a correlation expression as a function of time, space, and frequency. The comparison of a rotational MS scenario with a non-rotating MS scenario shows that the rotation has a considerable effect on both the amplitude and the period of oscillations of the CCF. In any case if we break the uniform DOA assumption for the incoming propagation waves, or the omnidirectional assumption for the MS antenna element, the effect of rotation is more considerable. Moreover, the mathematical model to represent this correlation function will be different. In reality, the rotation of a user is not in the form of a pure rotation; therefore, statistical information on the rotational/orienatational movements of the MS/user is necessary to provide the precise form of the CCF. Overall, this model introduces a non-stationary random process to characterize the propagation environment considering MS rotation, with exception of a narrowband communication, when either the MS angular velocity or the MS speed is zero.

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