LETTER

Impact of the Line-of-Sight Propagation Component on the Orthogonality Factor of the Synchronous DS-CDMA Uplink

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SUMMARY This paper investigates a modifying orthogonality factor for synchronous DS-CDMA uplink in dispersive Rician multipath fading channels, which reflects upon the effects of specular path power as well as decaying channel characteristics. Using this investigation, the orthogonal factors in indoor environments are evaluated and compared with the various parameters such as decaying factor, line-of-sight component, and the number of multipaths.

key words: *orthogonality factor, spread spectrum communication, Rician fading channels*

1. Introduction

Synchronous direct sequence code-division multiple-access (DS-CDMA) uplink transmission was proposed for reducing the effects of multiple access interference (MAI) [1], [2], with the additional benefit of having a lower multi-user detection, or interference cancellation complexity than asynchronous systems [3]. Hence, synchronous uplink DS-CDMA is appealing in the context of future broadband communication systems [4], [5], with the advent of accurate adaptive timing advance control, which is readily achievable in low-mobility indoor and/or pedestrian environments [1], [6]. Naturally, achieving perfect timing advance control may be elusive and hence the concept of uplink orthogonality factor has been introduced for the sake of quantifying the effects of time-delay misalignment among the different users on the maximum degree of orthogonality achievable, in the synchronous DS-CDMA uplink [7], [8]. However, previous studies [7], [8] have only considered the effect of channel dispersion, while neglecting the impact of having a specular component. In reality, the indoor channel often exhibits a strong line-of-sight (LOS) component [9], and therefore this contribution quantifies the impact of the appropriately modified orthogonality factor (OF) owing to the presence of a direct LOS path, in Rician multipath fading environments.

2. Channel Model

This paper considers a typical synchronous DS-CDMA uplink such as that described in [1], [2]. The Rayleigh fading channel model is modified by incorporating a known and constant direct LOS component, $\alpha e^{j\phi_\alpha}$, in the first tap of the dispersive tapped delay line channel model. This model reflects Rician fading in the first path, which was also considered in [10]. When communicating over dispersive fading channels, in addition to the dominant stationary LOS signal component, a multiplicity of differently delayed random multipath signal components arriving at different angles are encountered. In this letter, we assume the L-ray channel impulse response (CIR) shown in Fig. 1, having L Rayleigh faded paths, including (L-1) delayed paths, where τ_i is the time delay of each of the Rayleigh faded paths. A negative exponentially decaying multipath intensity profile (MIP) was considered, which is described as $E[\{\beta_l^{(k)}\}^2] = \Omega_0^{(k)} e^{-\delta l},\ for\ \delta > 0$, where $\beta_l^{(k)}$ refers to the Rayleigh distributed envelope of the lth faded path of the kth user, $\Omega_0^{(k)}$ is the power of the first faded path, while δ reflects the rate at which the decay of the average path strength as a function of path delay occurs.

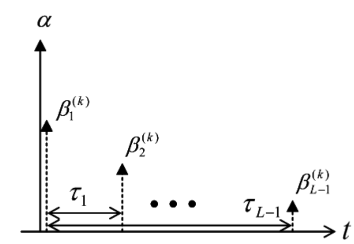

Fig. 1 Delay profile model.

3. Uplink Orthogonality Factor

Recently, the concept of Orthogonality Factor (OF) has been introduced as a measure of the grade of orthogonality for the intra-cell interfering signals received by a particular user. The OF is an important and useful parameter for simple capacity assessments at system level, as well as for network planning [11]. More quantatively, an OF of zero corresponds to perfect orthogonality, while an OF of unity implies a complete loss of orthogonality. In this section, the concept of uplink OF is developed for the sake of quantifying the impact of the LOS component.

3.1 Uplink Orthogonality Factor

The OF between a pair of users is defined as $\alpha_{OF} = \frac{\Gamma_T}{\Gamma_N}$, where Γ_T is the signal-to-total interference power ratio (STIR) and $\Gamma_N$is the signal-to-spillover interference power

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ratio (SSIR) for the pair of users considered. The spillover interference power quantified in the SSIR is the particular fraction of the total interference power that is not cancelled after the despreading operation at the output of the correlation-based receiver [3] and hence can only be reduced by a factor proportional to the spreading factor used. The OF quantifies the proportion of the interference that one of the users inflicts upon the other user of a pair, when both of them employ the same scrambling code, with respect to the interference imposed, when they use different scrambling codes. The latter interference scenario would hence correspond to encountering intercell interference [3].

Using a time dispersive CIR having an equal power per CIR tap, the resultant Signal-to-Noise Ratio (SNR) encountered when using Maximal Ratio Combining (MRC) is given as the sum of the individual CIR tap SNRs, i.e. by $\Gamma = \sum_{l=1}^{L} \Gamma_l$, where L is the number of CIR taps. During the calculation of the SSIR, the associated RAKE receiver's branch SNRs can be approximated as $\Gamma_{N,l} \approx \frac{a_l}{\sum_{m=1}^{L} a_m \gamma_{l,m}}$ where a_l is the power associated with the l-th CIR path of the desired signal, $a_m$is the power associated with the m-th CIR path of the interfering signal, while the interference factor $\gamma_{l,m}$ quantifies the fraction of interference power imposed by the m-th interfering path that cannot be cancelled owing to the lack of orthogonality during the detection of the l-th path of the desired signal. The value of the interference factor $\gamma_{l,m}$ depends on the relative delay of the l-th and m-th paths, and it tends to unity, when their relative misalignment is high, while it approaches zero, if they are perfectly aligned. The expression of $\Gamma_{N,l}$is only approximate, because the RAKE receiver branches typically experience an unequal noise power. The corresponding STIR of the RAKE-combiner branches used for the calculation are given as $\Gamma_{T,l} = \frac{a_l}{\sum_{m=1}^{L} a_m}$. From this point on, we set $\sum_{l=1}^{L} a_l = \sum_{m=1}^{L} a_m$ for all users, assuming that all the users have the same average power at the receiver as a result of a perfect power control strategy. Hence, the orthogonality factor can be approximated as

$$\alpha_{OF} = \frac{1}{\sum_{l=1}^{L} \frac{a_l}{\sum_{m=1}^{L} a_m \gamma_{l,m}}} \tag{1}$$

3.2 Uplink Orthogonality Factor Including the LOS Component

The RAKE receiver finger associated with the first resolvable path is assumed to track only the specular path, while the Rayleigh faded multipath components simply contribute to the interference [10]. Upon including the effect of the LOS component, the branch SNRs can be revised as follows

$$\Gamma_{N,l} \approx \frac{a_l}{\sum_{m=1}^{L} a_m \gamma_{l,m}} = \begin{cases} \frac{\alpha^2}{\sum_{m=1}^{L} a_m \gamma_{l,m}}, & l = 1 \\ \frac{a_l}{\sum_{m=1}^{L} a_m \gamma_{l,m}}, & l \geq 2 \end{cases}, \tag{2}$$

where $a_1 = \alpha^2$ for $m = 1$ as well as $l = 1$. The branch SNRs required for the STIR calculation are given as

$$\Gamma_{T,l} = \frac{a_l}{\sum_{m=1}^{L} a_m} = \begin{cases} \frac{\alpha^2}{\sum_{m=1}^{L} a_m}, & l = 1 \\ \frac{a_l}{\sum_{m=1}^{L} a_l}, & l \geq 2 \end{cases}, \tag{3}$$

where again, we have $a_1 = \alpha^2$ for $m = 1$ as well as $l = 1$. The OF includes the effect of the LOS component can therefore be approximated as

$$\begin{aligned} \Gamma_{OF\_LOS} &= \frac{1}{\sum_{l=1}^{L} \frac{\alpha_l}{\sum_{m=1}^{L} a_m \gamma_{l,m}}} \\ &= \begin{cases} \frac{1}{\sum_{l=1}^{L} \frac{\alpha^2}{\sum_{m=1}^{L} a_m \gamma_{l,m}}}, & l = 1 \\ \frac{1}{\sum_{l=1}^{L} \frac{a_l}{\sum_{m=1}^{L} a_m \gamma_{l,m}}} & l \geq 2 \end{cases}, \end{aligned} \tag{4}$$

where $a_1 = \alpha^2$ for $m = 1$ as well as $l = 1$, as before.

3.3 Assumptions Concerning $\gamma_{l,m}$

In the synchronous uplink the arrival time of the LOS path associated with the first RAKE receiver branch may be assumed to be synchronous, but the remaining branches are asynchronous. Therefore, the factor $\gamma_{l,m}$ is assumed to be

$$\gamma_{l,m} = \begin{cases} 0, & \text{if } l = m = 1 \\ 1, & \text{otherwise} \end{cases} \tag{5}$$

Secondly, for the sake of implicitly we assumed that the paths arriving from different users in the same order to be supposed to be aligned in time. Thus, the factor γ is assumed to be

$$\gamma_{l,m} = \begin{cases} 0, & \text{if } l = m \\ 1, & \text{otherwise} \end{cases} \tag{6}$$

Finally, the factor $\gamma_{l,m}$ may be expressed by taking into account the misalignment-related constraint in [5], yielding

$$\gamma_{l,m} = \begin{cases} \gamma_m(\tau), & \text{if } l = m = 1 \\ 1, & \text{otherwise} \end{cases} \tag{7}$$

where the interference-related factor $\gamma_{l,m}$ is defined between one of the paths of a user and another path of an asynchronous interferer having a relative delay of τ. For a misalignment error below 1/4 of a chip period, the value of the factor $\gamma_{l,m}$ remains below 0.16 [8].

4. Results and Conclustions

In this paper, α^2/Ω_0 is the ratio of the specular power relative to the average power of the first scattered path. Indoor radio channel measurements show that in these environments Rician distributions occur, which typically exhibit K-factors ranging from 2 dB to 7 dB [12]. Note that a more realistic profile model may be the exponential MIP. In our investigations the MIP decay exponent δ was set to 0.2 and 1.0 in order to quantify the effects of two extreme scenarios [9]. Table 1 shows a range of values for the uplink OF, which were generated under different assumption based on (9), (10) and (11) in conjunction with the decay factor δ

Table 1 Orthogonality factors based on Eqs. (5), (6) and (7).

$\frac{\alpha^2}{\Omega_0}$	MIP decay factor, δ	L=3			L=5		
		OF based on Eq. (5)	OF based on Eq. (6)	OF based on Eq. (7)	OF based on Eq. (5)	OF based on Eq. (6)	OF based on Eq. (7)
3 dB	0.2	0.565	0.530	0.653	0.736	0.702	0.789
	1.0	0.240	0.238	0.380	0.269	0.267	0.406
0 dB	0.2	0.787	0.653	0.830	0.896	0.810	0.916
	1.0	0.430	0.414	0.542	0.473	0.455	0.577

ranging from 0.2 to 1.0, where the ratio α/Ω_0 was set to 0 dB and 3 dB, assuming that the number of paths was either three or five. Intuitively, as the parameter δ increases, the received power associated with the main LOS path increases, resulting in a higher specular SIR. Furthermore, as the number of paths decreases, the effect of interpath interference decreases, significantly reducing the OF as a result of the higher specular SIR. However, the associated reduced number of resolvable multipath components is expected to decrease the achievable multipath diversity gain of the RAKE combiner. The effects of these two appointing trends have to be quantified in terms of the achievable BER. In Table 1, we can see undesirable increases of the OF as L increases. Therefore, it is expected that performance gains can be attained with the advent of a adaptive timing-advance aided synchronous transmission low-delay-spread indoor environments. When the MIP decays rapidly in conjuction with $\delta = 0.2$, the OF at $\alpha^2/\Omega_0 = 0$ dB and $L = 3$ becomes similar to that associated with $\alpha^2/\Omega_0 = 3$ dB and $L = 5$. Thus, we arrive at a similar OF with the advent of higher ratios of α^2/Ω_0 even in more dispersive environments exhibiting a higher number of resolvable paths, provided that the ratio of the LOS-power to the scattered power is comparatively high. This shows that both the OF and the BER occurring from the orthogonality by using quasi-synchronous transmissions may be reduced in comparison to that achieved by higher-order RAKE combining. By contrast, when we have a rapidly-decaying CIR associated with $\delta = 1.0$, the amount of misalignment is more effective than the number of multipaths on the value of OF. However, the synchronization for the arrival time of the first RAKE receiver branch signal can be readily achieved by powerful state-of-art synchronization techniques [3]. In summary, the letter studied the impact of various propagation effects on the orthogonality factor of synchronous DS-CDMA uplink scenarios in dispersive Rician multipath fading channels, quantifying the effects of the specular path's power as well as those of the MIP decay factor. The achievable OF value depends upon the specular path power, on the number of paths as well as on the decay exponent of the MIP.

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