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Reverse Link Performance of a Generalized MC-CDMA Systems for Multipath Fading Channel

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ABSTRACT- In this paper a multicarrier Code-division Multiple-access (MC-CDMA) system is proposed. The system is analyzed with a conventional correlator type receiver. Also A new expression of signal-to-interference-noise-ratio (SINR) and Bit error rate (BER) for single cell MC-CDMA wireless system over a Nakagami-m distributed frequency selective multi-path fading channel with perfect power control condition is derived and investigated. The performance of MC-CDMA over the frequency selective multipath fading channel is examined with varying the number of users and, the number of signal propagation path L respectively. From the simulation results we have seen that the SINR and BER performance is affected by these parameters. The result of the analysis will provide relevant information to design the physical layer protocol for 4G mobile communications system.

KEYWORDS: multi-path fading, SINR, power control, MC-CDMA, Nakagami-m distribution.

1. INTRODUCTION

Recently, novel multicarrier (MC) code-division multiple-access (CDMA) schemes have been suggested due to support high data rate services over hostile radio channels [1]. A signal-to-noise ratio (SNR) of the use of sets of multiple spreading sequences per user in MC CDMA has been investigated for Rayleigh fading channel [2]. A SNR of MC Direct-sequence (DS)-CDMA systems with Rake receivers over multipath fading channel has been evaluated [8]. A channel pre-equalization for the up-link of MC-CDMA systems was investigated [3]. An optimization criterion based on the maximization of the signal-to-interference plus noise ratio (SINR) at the base station while constraining the transmitted power by the mobile stations was studied over Rayleigh fading channels. However, they have carried out their research in the area by considering the mobile wireless channels either as an AWGN channel or a Rayleigh distributed flat fading channel or frequency selective fading channel. Very recently, the Nakagami-m distributed channel has drawn considerable attention of' the researchers [4] because it is a more realistic model then the others. This generic channel model is used, since the Nakagami- distribution is a generalized distribution, which often gives the best fit to land-mobile and indoor-mobile multipath propagation environments, as well as to scintillating ionospheric radio links [4]. A good fit to these widely varying propagation scenarios is achieved by varying the single parameter of in the Nakagami- distribution [5,6]. Furthermore, the Nakagami- distribution offers features of analytical convenience, as it has been shown in numerous treatises [5] and also in this contribution.

However, SINR and BER of the generalized MC-CDMA systems has not been published yet. In this paper, a new SINR has been analyzed for a generalized MC-CDMA systems over Nakagami-*m* multipath fading channels. The reverse link of proposed MC-CDMA mobile communication system who's SINR will be analyzed in this paper is shown in fig. 1. The paper is organized as follows. In Section 2 the MC-CDMA system as well as the channel model is presented. In Section 3, we analyze the statistic of the decision variable. Section 4 describe the numerical results. Finally discussion is stated in the last section.

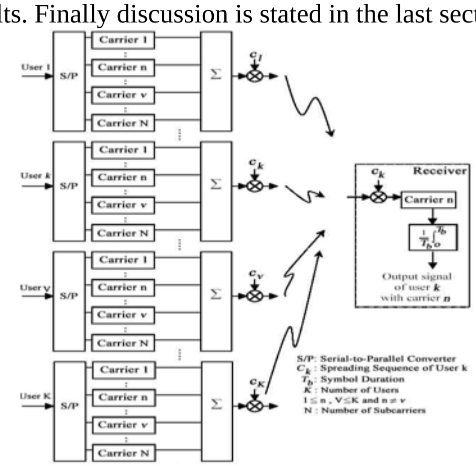

Fig. 1: Block diagram of proposed MC-CDMA systems

2. MC-CDMA WIRELESS SYSTEM MODEL

1. Transmitted Signal Model

The transmitter schematic of the kth user is shown in Fig. 1 for the MC-CDMA system. At the transmitter side, the binary data stream having a bit duration of T_b is serial-to-parallel converted to N parallel substreams.

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The new bit duration of each substream or the symbol duration is $T_s=NT_b$. After serial-to-parallel conversion, the nth substream modulates a subcarrier frequency f_n using binary phase shift keying (BPSK) for n=1,2,……N. Then, the N subcarrier-modulated substreams are added in order to form the complex modulated signal. Finally, spectral spreading is imposed on the complex signal by multiplying it with a spreading code. Therefore, the transmitted signal of user can be expressed as [7]

$$S_k(t)=\sum_{n=1}^{N}\sqrt{2P_k}\, b_{kn}(t)\, c_k(t)\cos(\omega_n t+\phi_{kn}) \qquad (1)$$

Where P_k represents the transmitted power per subcarrier, while{ $b_{kn}(t)$ } , {$c_k(t)$}, {f_n }, and {ϕ_{kn} } represent the data stream, the DS spreading waveform, the subcarrier frequency set and the phase angles introduced in the carrier modulation process. The data stream's waveform $b_{kn}(t)$ consists of a sequence of mutually independent rectangular pulses of duration T_s and of amplitude +1 or -1 with equal probability. The spreading sequence $c_k(t)$ denotes the signature sequence waveform of the kth user, assumes values of +1 or -1 with equal probability.

2. CHANNEL MODEL

As seen from the fig. 1, the kth transmitted signal, $S_k(t)$ is transmitted through a channel, $h_k(t)$. We assume that the channel between the kth transmitter and the corresponding receiver is a Nakagami-m fading channel with L multi-path. The complex low-pass equivalent representation of the impulse response experienced by subcarrier n of user k is given by [7]

$$h_{kn}(t)=\sum_{l}^{L}\alpha_{nl}\delta(t-\tau_{kl})\exp(-j\psi_{nl}) \qquad (2)$$

where α_{nl} ,τ_{kl} and ψ_{nl} represent the attenuation factor, delay and phase-shift for the l^{th} multipath component of the channel, respectively, while L is the total number of diversity paths and $\delta(t)$is the Kronecker-Delta function. We assume that the phases ψ_{nl} in "(2)," are independent identically distributed (i.i.d.) random variables uniformly distributed in the interval $[0, 2\pi]$, while the L multipath attenuations α_{nl} in "(2)," are independent Nakagami random variables with a probability density function (pdf) of [8]

$$P(\alpha_{nl})=\frac{2m^m\alpha_{11}^{2m-1}e^{-\frac{m}{\Omega}\alpha_{nl}^2}}{\Gamma(m)\Omega^m}\ ,\alpha_{nl}\geq 0 \qquad (3)$$

where Γ (.)is the gamma function, and m is the Nakagami-m fading parameter, which is equal to $m=E^2[(\alpha_{nl})^2]\ /\ Var[(\alpha_{nl})^2]$. The parameter m of the amplitude distribution characterizes the severity of the fading over the l^{th} resolvable path. The parameter , Ω_{nl} is the second moment of α_{nl}, i.e., $\Omega_{nl}= E[(\alpha_{nl})^2]$.

3. RECEIVED SIGNAL

In this paper, a single-cell MC-CDMA systems are considered, where the total number of asynchronous users is K and each mobile station has N subcarriers. Furthermore, it is assumed that the chip rate and the bit rate of message signals are fixed so that the processing gain, G, is fixed by the ratio of the chip rate and the bit rate. Under these assumptions, when K signals obeying the form of "(1)," are transmitted over the frequency-selective fading channels characterized by "(2)," the received signal including the other-user interference, fading and the background noise at the base station can be modeled as

$$r_k(t)=\sum_{k=1}^{K}\sum_{n=1}^{N}\sum_{l=1}^{L}\sqrt{2P_k}\,\alpha_{nl}\, b_{kn}(t-\tau_{kl})\, c_k(t-\tau_{kl})\cos(\omega_n t+\varphi_{kn}) + n(t) \qquad (4)$$

where $\varphi_{kn}= \phi_{kn} - \psi_{nl} - \omega_n\tau_{kl}$, which is assumed to be an i.i.d. random variable having a uniform distribution in $[0,2\pi]$, while n(t) represents the additive white Gaussian noise (AWGN) with zero mean and double-sided power spectral density of $N_0/2$.

3.1 Decision Statistics

In this section, we analyze the statistics of the decision variable of Z_{kn}. Let us assume that the desired user is the first user. Let the correlation between the signals of the k-th mobile station with carrier n and signals of the V-th mobile station with carrier v. With no loss of generality, it can be assumed also that τ_{11}=0 and φ_{11}=0.Then the output of the matched filter for the k-th mobile station using n-th subcarrier is

$$Z_{kn}=\int_0^{Tb} r_k(t)\, c_k(t)\cos(\omega_n t)\,dt=\int_0^{Tb}\Big[\sum_{k=1}^{K}\sum_{n=1}^{N}\sum_{l=1}^{L}\sqrt{2P_k}\,\alpha_{nl} b_{kn}(t-\tau_{kl})c_k(t-\tau_{kl})\cos(\omega_n t+\varphi_{kn})\Big]c_k(t)\cos(\omega_n t)\,dt+\int_0^{Tb} n(t)\, c_k(t)\cos(\omega_n t)dt$$

$$=D+\sum_{l=1}^{L}I_1+\sum_{\substack{n=1\\ n\neq v}}^{N}\cdot\sum_{l=1}^{L}I_2+\sum_{k=2}^{K}\sum_{l=1}^{L}I_3+\sum_{k=2}^{K}\sum_{\substack{n=1\\ n\neq v}}^{N}\sum_{l=1}^{L}I_4+Z=D+Z1+Z2+Z3+Z4+Z \qquad (5)$$

where Z is contributed by n(t) of "(4)," which is a Gaussian random variable with zero mean.

3.1.1 Desired Term D

From "(5),"

$$D=\int_0^{Tb} \sqrt{2P_k}\ \alpha_{11l}\ b_{11}(t)\ c_1^2(t)\cos(\omega_n t)\cos(\omega_n t)\,dt$$

$$=\sqrt{P_k/2}\ \alpha_{1l} b_{11}(T_b)T_b,$$ Here $c_1^2(t)=1$ and $\int_0^{Tb} b_{11}(t)\cos 2\omega_n t]dt=0$ for $\omega_c >> 2/T_b$

$$E[D^2]=T_b^2 E[\sqrt{P_k/2}]^2 E[\alpha_{1l}]^2=T_b^2 P_k \alpha^2_{1l}/2$$

3.1.2 Interference Term

The output of the correlator matched to the n-th subcarrier, l th path, and the reference user associated with k=1 contains four type of interference in (5):

(i) Interference due to the remaining L-1 paths ≠ l, on the same carrier n from the same user k=1.

(ii) Interference due to the remaining L-1 paths≠l, from the other carrier ≠n from the same user k=1.

(iii) Interference due to the L paths from the same carrier n from the other user k >1.

(iv) Interference due to the L paths from the others carrier ≠n from the other user k >1.

It is readily shown that R1, R2, R3, R4, have a zero mean hence, we are only interested in their variances. Following the mathematical procedure in [9],

$$Var(Z1)=\sigma_1^2=\sum_{l=1}^{L} E[P_k]\,\Omega\,T_b^2/(6G) \qquad (6)$$

$$Var(Z2)=\sigma_2^2=0 \qquad (7)$$

$$Var(Z3)=\sigma_3^2=\sum_{k=2}^{K}\sum_{l=1}^{L} E[P_k]\Omega T_b^2/(6G) \qquad (8)$$

$$Var(Z4)=\sigma_3^2=\sum_{k=2}^{K}\sum_{n=1}^{N}\sum_{l=1}^{L} E[P_k]\Omega T_b^2/(6G) \qquad (9)$$

Thus MAI power $=\sigma^2_{MAI}=\sigma_1^2+\sigma_2^2+\sigma_3^2+\sigma_4^2$

$$=\sum_{l=1}^{L} E[P_k]\,\Omega\,T_b^2/(6G)+0+\sum_{k=2}^{K}\sum_{l=1}^{L} E[P_k]\,\Omega\,T_b^2/(6G)+\sum_{k=2}^{K}\sum_{n=1}^{N}\sum_{l=1}^{L} E[P_k]\,\Omega\,T_b^2/(6G) \qquad (10)$$

3.1.3 Noise Term Z

From "(5)," $Z=\int_0^{Tb} n(t)\ c_1(t)\cos(\omega_n t)\,dt$, Now

$$Var(Z)=E[Z^2]=\sigma^2_N=N_0T_b/4 \qquad (11)$$

Hence, conditional signal-to-noise-interference-ratio conditioned on α_{11}

$$SNIR\alpha_{1l}=\frac{D}{\sigma^2_{MAI}+\sigma^2_N}=\alpha^2_{11}/\Big(\frac{1}{3P_kG}\Big[\sum_{l=1}^{L} E[P_k]\Omega+\sum_{k=2}^{K}\sum_{l=1}^{L} E[P_k]\Omega+\sum_{k=2}^{K}\sum_{n=1}^{N}\sum_{l=1}^{L} E[P_k]\Omega\Big]+N_0/2E_b\Big) \qquad (12)$$

Where, energy per bit $E_b=P_kT_b$ and we assuming α_{11}^2 is a random variable with Nakagami-m distribution."(12)." is the generalized expression of conditional SINR conditioned on α_{11}.

Now we will consider Perfect power control condition For Perfect power control E $[P_k]=P_k\ \forall$ k, i.e., the set of power level for the K-1 interfering users are constant. Hence,

SINR

$$=\alpha^2_{11}/\Big(\frac{1}{3G}[L\Omega+(K-1)L\Omega+(K-1)NL\Omega]+N_0/2E_b\Big)$$

$$=\alpha^2_{11}/\Big(\frac{1}{3G}[\Omega(LK+NLK-NL)]+N_0/2E_b\Big) \qquad (13)$$

Unconditional SINR can be derived as below,

$$SINR=\int_0^{\alpha} SINR_{\alpha 11}P(\alpha_{11})\,d\alpha_{11}$$

$$=\Omega/\Big(\frac{1}{3G}[\Omega(LK+NLK-NL)]+N_0/2E_b\Big) \qquad (14)$$

4. NUMERICAL RESULTS

To mitigate near-far problem, power control must be implemented in MC-CDMA systems. Here, the performance parameters, the SINR of the MC-CDMA system in case of perfect power control have been evaluated. To draw all the curves it is assumed that, Ω= 1. In fig. 2, SINR is plotted with the number of simultaneously active users K using L parameters. E_b/N_0=20dB; L=1, 2, 4 and used to draw the three curves of fig. 2. From fig. 2, it is observed that keeping all other parameter constant, if the number of simultaneously active user is increased, the SINR decreases.

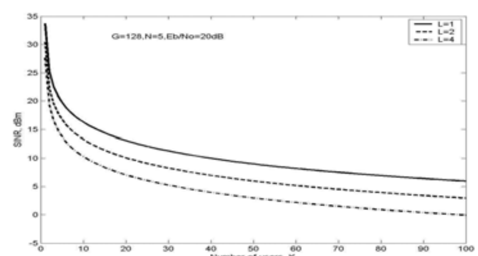

Fig. 2. SINR with the number of users for MC-CDMA system with perfect power control.

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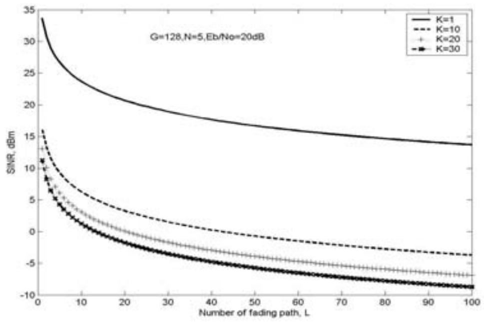

Fig. 3: SINR with the number of fading path for MC-CDMA system with perfect power control.

The variation of SINR with the number of propagation path L is shown in fig. 3. From fig.3 it is evident that if the number of fading path is increased, the SINR decreases. It can be explained as below. As the number of propagation path increases, the delay spread and hence the inter-symbol interference (ISI) increase, which in turn increase the MAI decreasing the SINR.

In fig.4, the variation of BER versus the number of simultaneously active users is drawn. It is observed that as the number of simultaneously active user increases, the BER of MC-CDMA system increases indicating the degradation of system performance. As the MAI increases with the increase of simultaneously active user, BER increase consequently. It is also observed that, BER decreases with the increase of the fading parameter *m*. The value of m indicates the severity of fading of the channel. Higher value of m indicates the less severe fading. Hence, BER decrease with the increase of the value of m. if we take 10^{-3} or less as the acceptable BER, then from fig. 4, it is seen that for L=1 & m=10, the allowable active user at a time can be approximately 135; for L=4 & m=10, the number reduced to 40. But for m=1, the BER is always grater than 10^{-3} for any value of L.

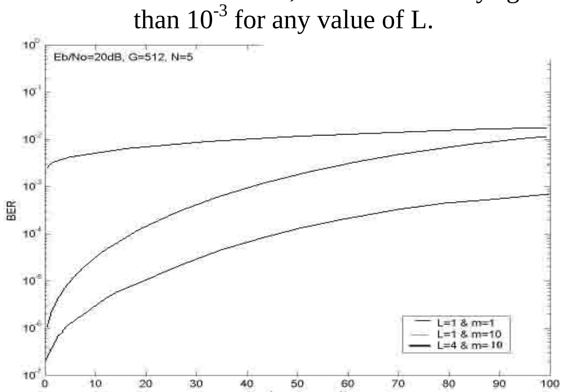

Fig. 4: BER versus the number of users for non-cellular MC-CDMA system with perfect power control.

5. DISCUSSION

The reverse link performance of MC-CDMA wireless communication system over a Nakagami-m distributed frequency selective multi-path fading channel considering perfect power control has been analyzed in this paper. A new method for the analysis of SINR performance of the generalized MC-CDMA for the reverse link has been presented. From the results, we concluded that the proposed MC-CDMA is an attractive wireless multiple access candidate, which is capable of interworking with the existing 2G and 3G CDMA system, while providing an evolutionary path for future 4G networks without rigid.

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