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Performance of an Orthogonal Multicarrier CDMA System over Rayleigh/Rician Fading Channels

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Abstract

We consider an improved multicarrier(MC) CDMA system that combines both DS-CDMA with a concatenated orthogonal/PN spreading sequence and MC modulation. This system incorporates the advantages of DS-CDMA with a concatenated sequence to achieve large user capacity and MC modulation technique to combat the effects of a multipath fading channel and intersymbol interference(ISI). Considering voice activity and imperfect sectorization, the system performance is analysed for the maximal ratio combiner(MRC) under a multicell, multiuser, and multipath Rayleigh/Rician fading channels. The performance of the system is improved much more for the single path fading channel compared to the multipath fading channel. Also the system is shown to have the more improved average bit error rate(BER) over the orthogonal MC-CDMA with the conventional PN sequence.

I. INTRODUCTION

A number of transmission and multiple access techniques have been proposed for future wireless communication systems. One of the latest proposed system is Multi-Carrier Code Division Multiple Access(MC-CDMA) which combines the advantages of Orthogonal Frequency Division Multiplexing (OFDM) with CDMA system.

Advantages of CDMA system are widely known: high immunity against multipath distortion, no need frequency planning, reasonable security etc[1]. In the case of using a concatenated orthogonal/ PN spreading sequence for the synchronous CDMA system, the user capacity is improved because an orthogonal sequence removes the time synchronized multiuser interference within the same cell and a long PN sequence mitigate the effect of asynchronous interference due to multipath[2].

On the other hand, MC modulation technique, also known as OFDM, has been studied for high data rate applications. The advantages of MC modulation technique are known such as the robustness against frequency selective fading channels and good spectral efficiency. The technique of MC modulation is based on transmitting data by dividing the high rate data stream into several low rate data streams, and then using these sub-channels to modulate different sub-carriers. By using a large

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number of sub-carriers, a high immunity against multipath spread can be obtained. If the symbol duration of each sub-stream is longer than multipath delay spread, the effect of ISI can be minimized.

A combination of MC modulation technique with CDMA system has been proposed in [3], [4]. Recently, E. Sourour and M. Nakagawa have analysed the performance of an orthogonal MC-CDMA system with a conventional PN sequence in a single cell environment[5].

In this paper, we consider an improved orthogonal MC-CDMA system that combines both DS-CDMA with a concatenated orthogonal/PN spreading sequence and MC modulation. This system incorporates the advantages of DS-CDMA with a concatenated sequence to achieve large user capacity and MC modulation technique to combat the effects of a multipath fading channel and ISI. Considering voice activity and imperfect sectorization, the system performance is analysed for the MRC under a multicell, multiuser, and multipath Rayleigh/Rician fading channels. The performance of the system is improved much more for the single path fading channel compared to the multipath fading channel. The system is shown to have the more improved average BER over the orthogonal MC-CDMA with the conventional PN sequence.

Ⅱ. SYSTEM MODELS

We consider the forward link transmission of an MC-CDMA system where the benefit of the concatenated sequence can be exploited. A multicell environment is shown in Fig. 1. Only the interference from 18 surrounding cells of the first two tiers is considered.

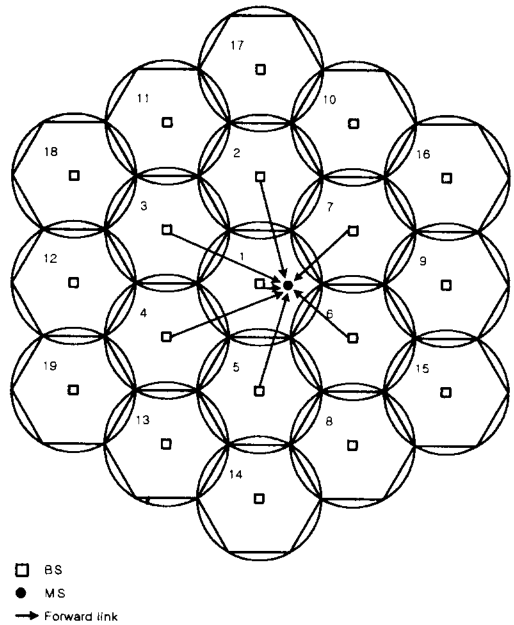


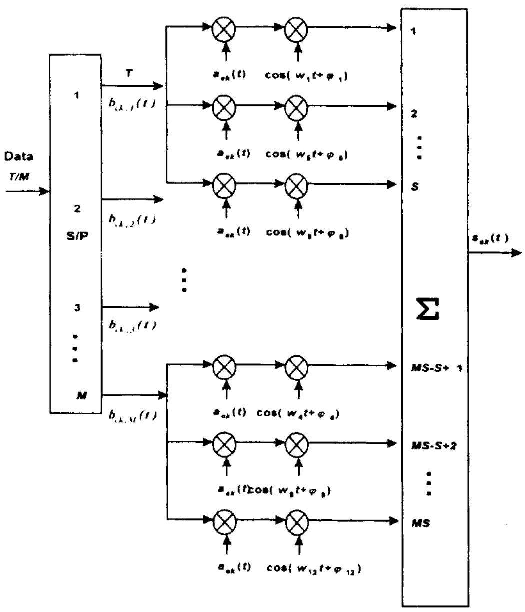
Fig. 1. Multicell environment.

2-1 Transmitter Model

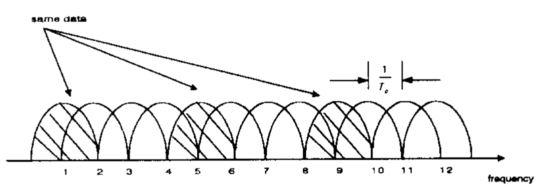
The block diagram of the orthogonal MC-CDMA transmitter and the frequency spectrum are shown in Fig. 2. At the transmitter, the data stream $b_{ck}(t)$ of rate M/T for the kth user of the cth base station (BS) is first converted into M parallel binary data sub-streams $(b_{ck,1}(t), b_{ck,2}(t), \cdots, b_{ck,M}(t))$ with duration T. Each sub-stream feeds S parallel branches such that the same data sub-stream exists on the S branches. The branch data is then spread by multiplying it with the spreading sequence $a_{ck}(t)$ associated with the kth user of the cth BS. This spreading sequence is a concatenated orthogonal/PN spreading sequence, in which an orthogonal sequence is concatenated with a long PN sequence to remedy their unsatisfactory and inhomogeneous behavior in a multipath environment[2].

The concatenated spreading sequence waveform $a_{ck}(t)$ can be written as

$$\begin{aligned} a_{ck}(t) &= \sum_{j=-\infty}^{\infty} a^j_{ck} P_{T_c}(t-jT_c) \\ &= \sum_{j=-\infty}^{\infty} d^j_c w^j_{ck} P_{T_c}(t-jT_c) \qquad (1) \end{aligned}$$



(a) Block diagram of an orthogonal MC-CDMA transmitter



(b) Fequency spectrum

Fig. 2. Block diagram of an orthogonal MC-CDMA transmitter and the frequency spectrum(M=4, S=3).

where $a^j_{ck} \in \{+1, -1\}$ is the concatenated spreading sequence for the kth user of the cth BS. $d^j_c \in \{+1, -1\}$ represents the PN m-sequence for the cth BS, and $w^j_{ck} \in \{+1, -1\}$ is the orthogonal Walsh-Hadamard(WH) code for the kth user of the cth BS. The long PN sequence has a period P_c which is much greater than a period N_c of the WH codes. $P_{Tc}(t)$ is the chip waveform which is a rectangular pulse with chip duration $T_c = T/N_c$.

Assuming BPSK modulation, the pth binary data stream $b_{ck,p}(t)$ on the υth branch modulates a carrier frequency $f_q = f_1 + q/N_c$ where f_1 is the lowest frequency of the carriers and $q = p + M(\upsilon - 1)$, $\upsilon = 1, 2, \cdots, S$. The carrier frequencies are equally separated by the chip rate $1/T_c$. The spectra of different carriers are mutually overlapped. The carrier frequencies are mutually orthogonal in the interval $[0, T_c]$. The multicarrier signal is obtained by the sum of different carriers.

The transmission BW is fixed to be the passband null-to-null BW $2/T_{c1}$, where T_{c1} is the PN code chip duration for the single carrier case. The chip duration T_c has the relation of $T_c = \frac{MS+1}{2} T_{c1}$. From $T_c = MT_b/N_c$ and $T_{c1} = T_b/N_{c1}$, the period N_c has the relation of $N_c = \frac{2M}{MS+1} N_{c1}$ where N_{c1} is the period of the WH codes for the single carrier case.

The transmitted signal to the kth user of the cth BS can be expressed as

$$\begin{aligned} s_{ck}(t) = \sqrt{2P_{ck}} \sum_{m=1}^{MS} \mathrm{Re}\{ b_{ck,p}(t) \\ \cdot a_{ck}(t) \exp(j2\pi f_m t + j\varphi_{c,k,m}\} \qquad (2) \end{aligned}$$

where P_{ck} is the power of the kth user for the cth BS and $p = 1 + [(m-1) \bmod M]$. $\varphi_{c,k,m}$ is the

mth carrier phase of the kth user for the cth BS.

Assuming there are K users belonging to the cth BS, the total signal transmitted by the cth BS is

$$s_c(t) = \sum_{k=1}^{K} \lambda_{ck} s_{ck}(t) \tag{3}$$

where λ_{ck} is the random variable that accounts for the voice activity factor of transmission, η. $\lambda_{ck}=1$ with probability η and $\lambda_{ck}=0$ with probability $1-\eta$. λ_{ck} is independent for different user and BS. It is assumed that all cells have the same number of users, and that all transmission power of all BS are the same. Also users are assumed to be uniformly distributed in a cell.

2-2 Channel Model

The channel model adopted for wireless communications consists of multipath fading, shadowing, and path loss.

2-2-1 Multipath Fading Channel

The multipath fading model for both Rayleigh and Rician channels is considered as[6]:

$$h_c(t) = \sum_{n=1}^{L} \alpha_{cn} \delta(t-\tau_{cn}) \tag{4}$$

where L is the number of resolvable multipath, δ is the unit impulse function, α_{cn} and τ_{cn} are the complex gain coefficient and the time delay of the nth path for the cth BS, respectively. α_{cn} is given by

$$\alpha_{c1} = \beta_c + \gamma_{c1} A_{c1} \exp(j\theta_{c1})$$
$$\alpha_{cn} = \gamma_{cn} A_{cn} \exp(j\theta_{cn}), \quad 2 \le n \le L. \tag{5}$$

$\gamma_{cn}A_{cn}$ and θ_{cn} are the attenuation and the phase shift of the nth path for the cth BS, respectively. A_{cn} is a Rayleigh distributed random variable and γ_{cn} is a constant for path strength. Without loss of generality, γ_{c1} and $E[A_{cn}^2]$ are normalized to be 1 so that γ_{cn}^2 can be seen as the relative power of the nth path to that of the first path. For Rayleigh fading channel, $\beta_c=0$ and $\gamma_{c1}=1$ since there is no specular path. θ_{cn} is assumed to be uniformly distributed in $[0, 2\pi]$. The time delay of the first path, τ_{c1}, is set to be zero without loss of generality so that τ_{cn} represents the time delay of the nth path relative to the first path.

2-2-2 Shadowing and Path Loss

For the forward link, the multi-user signals from the same BS to a mobile are time synchronous and they go through the same channel. The effect of shadowing and path loss on the power of all transmitted signals is the same. As a result, for a single cell environment, their effect can be ignored without loss of generality. However, for the multicell environment, due to independent shadowing and path loss of the signals from different BS, the variation in the received power cannot be ignored as for the case of the single cell environment. The signal power received from the cth BS due to lognormal shadowing and path loss becomes

$$P'_{ck} \propto P_{ck}\left(\frac{10^{(\xi_c/10)}}{d_c^r}\right) \tag{6}$$

where ξ_c is an independent Gaussian random variable for different BS with zero mean, d_c is the distance between the cth BS and the desired mobile, and r is the path loss exponent.

2-3 Receiver Model

The received signal at a mobile, $r(t)$, includes the signal from the local BS as well as the signal from 18 other neighboring cells. Thus the received signal is given by

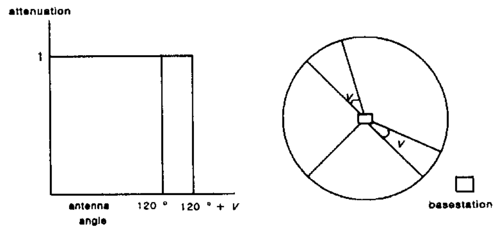
$$r(t)=\sum_{c=1}^{19}\sum_{k=1}^{K}\sum_{n=1}^{L}\lambda_{ck}\sqrt{\rho_c}\ Re\{\alpha_{cn}s_{ck}'(t-\tau_{cn}-\zeta_c)\}+n(t) \qquad (7)$$

where ρ_c is the relative attenuation of the received signal power from the cth BS over that of the first BS (i. e., $\rho_1=1$), ζ_c is the relative time delay of the signal from the cth BS over that of the first BS (i. e., $\zeta_1=0$), $s_{ck}'(t)$ is the complex representation of $s_{ck}(t)$, and $n(t)$ is additive white Gaussian noise (AWGN) with two-sided power spectral density $N_0/2$. ρ_c is given by

$$\rho_c=\left(\frac{d_1}{d_c}\right)^{\gamma}\frac{10^{(\xi_c/10)}}{10^{(\xi_1/10)}}. \qquad (8)$$

2-4 Imperfect Sectorization

The user capacity can be increased by dividing a cell into a number of sectors using directional antennas. Since practical antennas have sidelobes, imperfect sectorization occurs in practice[7]. We assume the antenna radiation patterns shown in Fig. 3 where antenna imperfections are modeled by the overlap angle v. The ratio of the total interference power received in a sectorized system and the total interference power received in a non-sectorized system denoted by, μ, can be derived as



(a) (b)

Fig. 3. (a) Radiation pattern model for imperfect directional antenna
(b) Sector coverage with an imperfect directional antenna with opening angle 120°.

$$\mu \triangleq \frac{\hat{P}_{\text{sectorized}}}{\hat{P}_{\text{non-sectorized}}}=\left(\frac{1}{D}+\frac{2v}{360}\right) \qquad (9)$$

where $\hat{P}$ is the interference power and D is the number of sectors.

Ⅲ. PERFORMANCE ANALYSIS

We first define the continuous time periodic cross-correlation function as

$$R^{x}_{1k,1i,mq}(k',\tau)=\int_0^T a_{1k}(t+k'T_c-\tau)\cdot a_{1i}(t+k'T_c)f[\frac{2\pi(m-q)t}{T}]dt \qquad (10)$$

where $f()$ is cos() or sin() according to c or s of x, respectively. Continuous time partial cross-correlation functions are defined as

$$R^{x}_{ck,1i,mq}(k_c',k_1',\tau)=\int_0^{\tau} a_{ck}(t+k_c'T_c-\tau)\cdot a_{1i}(t+k_1'T_c)f\left[\frac{2\pi(m-q)t}{T}\right]dt \qquad (11)$$

$$\hat{R}^{x}_{ck,1i,mq}(k_c',k_1',\tau)=\int_{\tau}^{T} a_{ck}(t+k_c'T_c-\tau)$$

$$\cdot\, a_{1l}(t+k_1{}'T_c)f[\frac{2\pi(m-q)t}{T}]\,dt. \quad (12)$$

The MRC with $B(\le L)$ branches is used under the assumption that the complex gain coefficient and the time delay of each path are perfectly estimated. The decision variable on the zeroth symbol associated with the qth carrier for the ith user of the first BS is given by

$$Z_{1,i}^{q,0} = \sum_{l=1}^{B}\int_{\tau_{1l}}^{\tau_{1l}+T} \cdot \mathrm{Re}\{\alpha_{1l}^{*}r'(t)\}\,\Psi_{1,i,q}(t-\tau_{1l})dt \quad (13)$$

where * denotes complex conjugate, $r'(t)$ is the complex representation of $r(t)$, and

$$\Psi_{1,i,q}(t)=a_{1l}(t)\cos(2\pi f_q t+\varphi_{1,i,q}).$$

Thus the decision variable with the ith user for the pth sub-stream of the first BS is given by

$$Z_{1,i,p}^{0}=\sum_{v=1}^{S}Z_{1,i}^{q,0} =\sqrt{P/2}\,T\Big\{b_{1,i,p}^{0}S\sum_{l=1}^{B}|\alpha_{1l}|^2+I_u+I_{m,1} +I_{m,2}+I_{m,3}+\sum_{c=2}^{19}F_c\Big\}+n_0 \quad (14)$$

where $q=p+M(v-1)$, $b_{1,i,p}^{0}$ is the zeroth symbol for the pth sub-stream of the ith user and the first BS. n_0 is given by

$$n_0=\sum_{v=1}^{S}\sum_{l=1}^{B}\int_{\tau_{1l}}^{\tau_{1l}+T}\mathrm{Re}\{\alpha_{1l}^{*}n(t)\} \cdot \Psi_{1,i,q}(t-\tau_{1l})dt. \quad (15)$$

I_u is the multiuser interference at the time synchronized path of the receiver for the first BS, given by

$$I_u=\frac{1}{T}\sum_{v=1}^{S}\sum_{l=1}^{B}\sum_{\substack{k=1\\ \ne i}}^{K} \cdot \lambda_{1k}|\alpha_{1l}|^2\cos(\varphi_{1,k,q}-\varphi_{1,i,q}) \cdot b_{1,k,q}^{0}R_{1k,1i,qq}^{c}(k_1{}',0). \quad (16)$$

$I_{m,1}$ is the multipath interference with the same carrier for the same user in the first BS, given by

$$\begin{aligned} I_{m,1}&=\frac{1}{T}\sum_{v=1}^{S}\sum_{l=1}^{B}\sum_{\substack{n=1\\ \ne l}}^{L}|\alpha_{1l}||\alpha_{1n}| \cdot \cos(\Phi_{1,i,q,n}-\Phi_{1,i,q,l}) \\ &\quad\cdot\{b_{1,i,q}^{-1}R_{1i,1i,qq}^{c}(k_1{}',k_1{}',\tau_{1n,1l}) + b_{1,i,q}^{0}\hat{R}_{1i,1i,qq}^{c}(k_1{}',k_1{}',\tau_{1n,1l})\} \\ &=\frac{1}{T}\sum_{v=1}^{S}\sum_{l=1}^{B}[\sum_{\substack{n=1\\ \ne l}}^{B}(same) + \sum_{n=B+1}^{L}(same)] \\ &=\frac{1}{T}\sum_{v=1}^{S}[I_{m,1}^{(1)}+I_{m,1}^{(2)}]. \end{aligned} \quad (17)$$

where $\tau_{cn,cl}=\tau_{cn}-\tau_{cl}$ and $\Phi_{c,k,m,n}=2\pi f_m(\tau_{cn}+\zeta_c)+\theta_{cn}+\rho_{c,k,m}$. $I_{m,1}^{(1)}$ is the additional correlation term because of having the same phase with the opposite polarity.

Using the relation

$$\sum_{l=1}^{B}\sum_{\substack{n=1\\ \ne l}}^{B}f(l,n) = \sum_{l=1}^{B-1}\sum_{n=l+1}^{B}\{f(l,n)+f(n,l)\}. \quad (18)$$

$I_{m,1}^{(1)}$ can be written as

$$I_{m,1}^{(1)}=\sum_{l=1}^{B-1}\sum_{n=l+1}^{B}|\alpha_{1l}||\alpha_{1n}|\cos(\Phi_{1,i,q,n}-\Phi_{1,i,q,l}) \cdot\{(b_{1,i,q}^{-1}+b_{1,i,q}^{+1})R_{1i,1i,qq}^{c}(k_1{}',k_1{}',\tau_{1n,1l}) +2b_{1,i,q}^{0}\hat{R}^{c}_{1i,1i,qq}(k_1{}',k_1{}',\tau_{1n,1l})\}. \quad (19)$$

$I_{m,1}^{(2)}$ are uncorrelated for all terms given by

$$I_{m,1}^{(2)}=\sum_{l=1}^{B}\sum_{n=B+1}^{L}|\alpha_{1l}||\alpha_{1n}|\cos(\Phi_{1,i,q,n}-\Phi_{1,i,q,l})$$
$$\cdot\{b_{1,i,q}^{-1}R_{1i,1i,qq}^{c}(k_1',k_1',\tau_{1n,1l})$$
$$+b_{1,i,q}^{0}\hat{R}^{c}_{1i,1i,qq}(k_1',k_1',\tau_{1n,1l})\} \quad (20)$$

$I_{m,2}$ is the multipath interference with the same carrier for the other users in the first BS. $I_{m,2}$ is uncorrelated for all the other users and the other paths given by

$$I_{m,2}=\frac{1}{T}\sum_{\substack{k=1\\ \neq i}}^{K}\sum_{v=1}^{S}\sum_{l=1}^{B}\sum_{\substack{n=1\\ \neq l}}^{L}\lambda_{1k}|\alpha_{1l}||\alpha_{1n}|$$
$$\cdot\cos(\Phi_{1,k,q,n}-\Phi_{1,i,q,l})$$
$$\cdot\{b_{1,k,q}^{-1}R_{1k,1i,qq}^{c}(k_1',k_1',\tau_{1n,1l})$$
$$+b_{1,k,q}^{0}\hat{R}^{c}_{1k,1i,qq}(k_1',k_1'\tau_{1n,1l})\}. \quad (21)$$

$I_{m,3}$ is the multipath interference with the other carriers for all users in the first BS. $I_{m,3}$ is uncorrelated for all users, the other carriers, and the other paths, given by

$$I_{m,3}=\frac{1}{T}\sum_{v=1}^{S}\sum_{\substack{m=1\\ \neq q}}^{MS}\sum_{l=1}^{B}\sum_{k=1}^{K}\sum_{\substack{n=1\\ \neq l}}^{L}\lambda_{1k}|\alpha_{1n}||\alpha_{1l}|$$
$$\cdot\{\cos(\Phi_{1,k,m,n}-\Phi_{1,i,q,l})$$
$$\cdot[b_{1,k,m}^{-1}R_{1k,1i,mq}^{c}(k_1',k_1',\tau_{1n,1l})$$
$$+b_{1,k,m}^{0}\hat{R}^{c}_{1k,1i,mq}(k_1',k_1',\tau_{1n,1l})$$
$$-\sin(\Phi_{1,k,m,n}-\Phi_{1,i,q,l})$$
$$\cdot[b_{1,k,m}^{-1}R_{1k,1i,mq}^{s}(k_1',k_1',\tau_{1n,1l})$$
$$+b_{1,k,m}^{0}\hat{R}^{s}_{1k,1i,mq}(k_1',k_1',\tau_{1,nl\,l})]\}. \quad (22)$$

F_c is the intercell interference from the cth BS given by

$$F_c=\frac{\sqrt{\rho_c}}{T}\sum_{v=1}^{S}\sum_{l=1}^{B}\sum_{k=1}^{K}\sum_{m=1}^{MS}\sum_{n=1}^{L}\lambda_{ck}|\alpha_{cn}||\alpha_{1l}|$$
$$\cdot\{\cos(\Phi_{c,k,m,n}-\Phi_{1,i,q,l})$$
$$\cdot[b_{c,k,m}^{-1}R_{ck,1i,mq}^{c}(k_c',k_1',\tau_{cn,1l})$$
$$+b_{c,k,m}^{0}\hat{R}^{c}_{ck,1i,mq}(k_c',k_1',\tau_{cn,1l})]$$
$$-\sin(\Phi_{c,k,m,n}-\Phi_{1,i,q,l})$$
$$\cdot[b_{c,k,m}^{-1}R_{ck,1i,mq}^{s}(k_c',k_1',\tau_{cn,1l})$$
$$+b_{c,k,m}^{0}\hat{R}^{s}_{ck,1i,mq}(k_c',k_1',\tau_{cn,1l})]. \quad (23)$$

The interferences consist of the mutually independent random variables. Thus, using the central limit theorem, the interferences are assumed to be Gaussian random variables with zero mean[6].

3-1 Rayleigh Fading Channel

For the concatenated sequence, the variance of I_u is zero. For the nonconcatenated sequence, the variance of I_u is given by $\frac{\eta(K-1)S}{2N_c}(\sum_{l=1}^{B}|\alpha_{1l}|^2)^2$ After some manipulations, one can obtain the following variances which are identical for both concatenated and nonconcatenated sequences. The variance of $I_{m,1}$ is given by

$$\mathrm{Var}(I_{m,1})=\frac{S}{N_c}\left\{\frac{1}{2}R_{ra}+\frac{1}{3}R\right\} \quad (24)$$

where

$$R_{ra}=\sum_{l=1}^{B}\sum_{\substack{n=1\\ \neq l}}^{B}|\alpha_{1l}|^2|\alpha_{1n}|^2. \quad (25)$$

$$R=\sum_{l=1}^{B}\sum_{n=B+1}^{L}|\alpha_{1l}|^2|\gamma_{1n}|^2. \quad (26)$$

Using the approximation

$$\sum_{l=1}^{B}|\alpha_{1l}|^4\cong(\sum_{l=1}^{B}|\alpha_{1l}|^2)^2/B,$$

$$R_{ra}\cong\frac{B-1}{B}(\sum_{l=1}^{B}|\alpha_{1l}|^2)^2 \quad (27)$$

The variances of $I_{m,2}$ and $I_{m,3}$ are given by

$$\mathrm{Var}(I_{m,2}) = \frac{\eta(K-1)S}{3N_c}\{R_{ra}+R\} \tag{28}$$

$$\mathrm{Var}(I_{m,3}) = \frac{\eta K}{4\pi^2 N_c}\sum_{v=1}^{S}\sum_{\substack{m=1\\ \neq q}}^{MS} \cdot \frac{1}{(m-q)^2}\{R_{ra}+R\}. \tag{29}$$

The variance of F_c is given by

$$\mathrm{Var}(F_c) = \eta E[\rho_c] \cdot \left\{\frac{KS}{3N_c} + \frac{K}{4\pi^2 N_c}\sum_{v=1}^{S}\sum_{\substack{m=1\\ \neq q}}^{MS}\frac{1}{(m-q)^2}\right\} \cdot \left\{\sum_{l=1}^{B}\sum_{n=1}^{B}|\alpha_{1l}|^2|\alpha_{cn}|^2 + \sum_{l=1}^{B}\sum_{n=B+1}^{L}|\alpha_{1l}|^2|\gamma_{cn}|^2\right\} \tag{30}$$

The variance of the output AWGN is given by

$$\mathrm{Var}(n_0) = \frac{N_0 T}{4} S\sum_{l=l}^{B}|\alpha_{1l}|^2. \tag{31}$$

The signal power is $\frac{P}{2}T^2(S\sum_{l=1}^{B}|\alpha_{1l}|^2)^2$

For the concatenated sequence, the conditional signal to noise ratio (SNR) is given by

$$SNR_{con} = (S\sum_{l=1}^{B}|\alpha_{1l}|^2)^2\left\{\frac{N_0}{2E_s}S\sum_{l=1}^{B}|\alpha_{1l}|^2 + \mu\,[\,\mathrm{Var}(I_{m,1}) + \mathrm{Var}(I_{m,2}) + \mathrm{Var}(I_{m,3}) + \sum_{c=2}^{19}\mathrm{Var}(F_c)]\right\}^{-1}. \tag{32}$$

where E_s is the energy per data symbol of one carrier. For the nonconcatenated sequence, the conditional SNR is given by

$$\mathrm{SNR}_{non} = (S\sum_{l=1}^{B}|\alpha_{1l}|^2)^2\left\{\frac{N_0}{2E_s}S\sum_{l=1}^{B}|\alpha_{1l}|^2 + \mu\,[\,\mathrm{Var}(I_\mu) + \mathrm{Var}(I_{m,1}) + \mathrm{Var}(I_{m,2}) + \mathrm{Var}(I_{m,3}) + \sum_{c=2}^{19}\mathrm{Var}(F_c)]\right\}^{-1}. \tag{33}$$

The average BER obtained by averaging over the probability density function(pdf) of the random variable $x = \sum_{l=1}^{B}|\alpha_{1l}|^2$ is given by

$$P_e = \int_0^\infty Q(\sqrt{\mathrm{SNR}(x)})f_X(x)\,dx \tag{34}$$

where $f_X(x)$ is the pdf of the random variable of x.

3-2 Rician Fading Channel

For the concatenated sequence, the variance of I_u is zero. For the nonconcatenated sequence, the variance of I_u is given by $\frac{\eta(K-1)S}{2N_c}(1+\sum_{l=2}^{B}|\alpha_{1l}|^2)^2$. Using the sameanalysis in the Rayleigh fading channel, the following variances are obtained.

$$\mathrm{Var}(I_{m,1}) = \frac{S}{N_c}\left\{\frac{1}{2}R_{ri} + \frac{1}{3}R\right\} \tag{35}$$

where R is the same with that of the Rayleigh fading channel and

$$R_{ri} \cong (1+\sum_{l=2}^{B}|\alpha_{1l}|^2)^2 - \frac{(\sum_{l=2}^{B}|\alpha_{1l}|^2)^2}{B-1} - 1. \tag{36}$$

The variances of $I_{m,2}$ and $I_{m,3}$ are given by

$$\mathrm{Var}(I_{m,2}) = \frac{\eta(K-1)S}{3N_c}\{R_{ri}+R\} \tag{37}$$

$$\mathrm{Var}(I_{m,3}) = \frac{\eta K}{4\pi^2 N_c}\sum_{v=1}^{S}\sum_{\substack{m=1\\ \neq q}}^{MS} \cdot \frac{1}{(m-q)^2}\{R_{ri}+R\} \tag{38}$$

The variance of F_c is given by

$$\mathrm{Var}(F_c)=\eta E[\rho_c]\left\{\frac{KS}{3N_c}+\frac{K}{4\pi^2N_c}\sum_{v=1}^{S}\sum_{\substack{m=1\\ \neq q}}^{MS}\frac{1}{(m-q)^2}\right\}\cdot\left\{(1+\sum_{l=2}^{B}|\alpha_{1l}|^2)\right.$$
$$\cdot(1+\sum_{n=2}^{B}|\alpha_{cn}|^2+\sum_{n=B+1}^{L}|\gamma_{cn}|^2). \qquad (39)$$

The variance of the output AWGN is given by

$$\mathrm{Var}(n_0)=\frac{N_0T}{4}S(1+\sum_{l=2}^{B}|\alpha_{1l}|^2) \qquad (40)$$

The signal power is $\frac{P}{2}T^2S^2(1+\sum_{l=2}^{B}|\alpha_{1l}|^2)^2$.

The average BER can be obtained in the same manner as before.

Ⅳ. NUMERICAL RESULT

We assume mobiles uniformly distributed in a cell, the equal number of users per cell, and the same channel parameter for signal transmitted by different BS. In the case of single carrier CDMA system, the relative power of each resolvable path are (0, −6, −8 dB) for Rayleigh fading channel[8]. It is assumed that the power ratio of the first path over the remaining path is 7 dB for Rician fading channel. The path loss exponent r is 4 and the standard deviation for lognormal shadowing is 8.

Fig. 4 and Fig. 5 show the average BER of MRC versus the ratio of averaged symbol energy over white noise for Rayleigh and Rician fading channels, respectively. For $M=S=1$, the number of path is 3 and the number of chips is 128. For $S=2$, the number of path is 2 and the number of branches of MRC is 2. For $S=4$, the number of path is 1 and the multipath interference is vanished. The performance of the system is improved much more for the single path fading channel compared to the multipath fading channel. Also the system is shown to outperform the MC-CDMA system with the conventional PN spreading sequence.

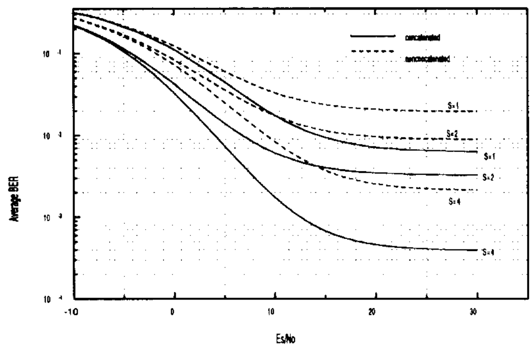


Fig. 4. Average BER of MRC versus E_s/N_o for Rayleigh fading channel. (M=1, K=20, η =1, D=1)

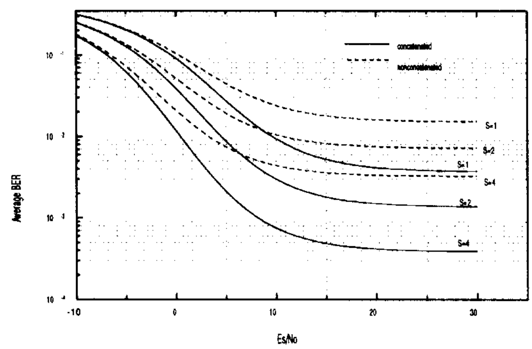


Fig. 5. Average BER of MRC versus E_s/N_o for Rician fading channel(M=1, K=20, η =1, D=1)

Fig. 6 and Fig. 7 show the average BER of MRC versus the number of user per cell for Rayleigh and Rician fading channels, respectively. As in the case of Fig. 4 and Fig. 5, larger user

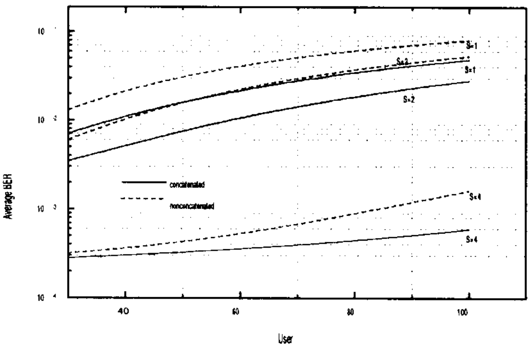


Fig. 6. Average BER of MRC versus user/cell for Rayleigh fading channel. (M=1, E_s/N_0=10 dB, η =0.375, D=3)

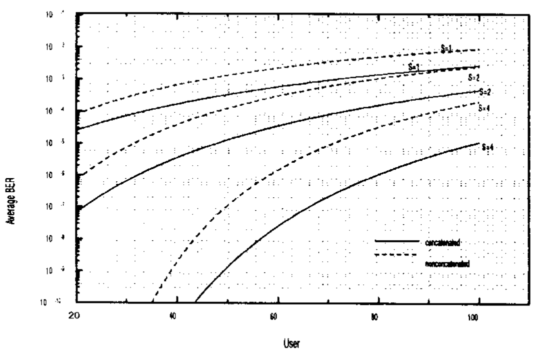


Fig. 7. Average BER of MRC versus user/cell for Rician fading channel(M=1, E_s/N_0=10 dB, η =0.375, D=3).

capacity is achieved for the single path fading channel compared with the multipath fading channel. Especially, the system is much more improved for the Rician fading channel compared to Rayleigh fading channel since the multiuser interference in the strong specular path is removed by the concatenated sequence.

Fig. 8 shows average BER versus overlap angle for the single path fading channel. The system performance decreases as the overlap angle due to imperfect sectorized antenna for both Rayleigh and

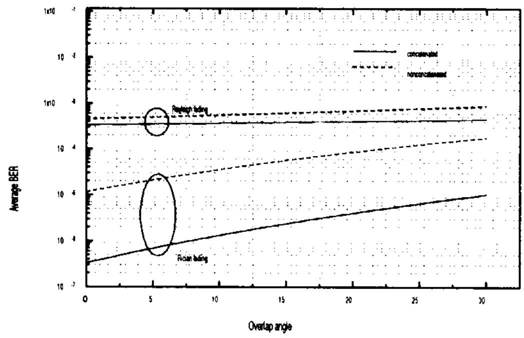


Fig. 8. Average BER versus overlap angle. (M=1, S=4, K=20, E_s/N_0=10 dB, η =1, D=3)

Rician fading channels. One can see that in the presence of imperfect sectorization the system is shown to outperform the MC-CDMA system with the conventional PN spreading sequence.

V. CONCLUSION

We have considered an improved orthogonal MC-CDMA system that combines both DS-CDMA with a concatenated orthogonal/PN spreading sequence and MC modulation. This system incorporates the advantages of DS-CDMA with a concatenated sequence to achieve large user capacity and MC modulation technique to combat the effects of a multipath fading channel and ISI. Considering voice activity and imperfect sectorization, the system performance is analysed for the MRC under a multicell, multiuser, and multipath Rayleigh/Rician fading channels. The performance of the system is improved much more for the single path fading channel compared to the multipath fading channel. The system is shown to have the more improved average BER over the MC-CDMA system with the conventional PN sequence. Especially, the performance has been improved much more for the Rician fading channel compared to the Rayleigh fading channel.

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