MICROCELLULAR CDMA MOBILE COMMUNICATIONS

Jiangzhou Wang
Dept. of Electrical and Electronics Engineering
University of Hong Kong, HONG KONG
Email: jwang@hkueee.hku.hk

ABSTRACT

Code division multiple access (CDMA) is becoming a very attractive technique for personal communications networks (PCN) and microcellular mobile communications. This paper evaluates the performance of a microcellular CDMA system by considering the effects of both intracell and intercell interference.

I. INTRODUCTION

Because of its well-known ability to both combat multipath and allow multiple users to simultaneously communicate over a channel, spread-spectrum techniques are being considered for use in cellular communication networks. A number of papers have appeared in recent literature that evaluate multiple-cell CDMA systems, by assuming a single layer of cells. This paper considers the performance of a cellular CDMA system in a multiple-cell mobile radio environment by assuming various layers of cells.

II. MATHEMATICAL MODEL

The transmitted signal for the kth CDMA user is given by

$$S_k(t) = \sqrt{2P_k}\, b_k(t) a_k(t) \cos(2\pi f_0 t + \theta_k), \quad (1)$$

where P_k is the average power of the signal, b_k(t) is a random binary sequence representing the data, a_k(t) is the spreading sequence, also modeled as a random binary sequence, f_0 is the carrier frequency and θ_k is a random phase. Each data bit has a duration of T_b seconds, each chip of the spreading sequence has duration T_c seconds, and the processing gain is defined as $N=T_b/T_c$.

Without loss of generality, the cellular channel is modeled as a flat Rayleigh fading channel. The channel between the kth user and the receiver of interest (namely the receiver in the base station of what we refer to as the first cell) is modeled by the complex lowpass equivalent impulse response

$$h_k(t) = \frac{1}{(d_{1,k})^{\gamma/2}} \beta_k \delta(t - \tau_k) \exp(j\eta_k) \quad (2)$$

where γ is a propagation exponent and $d_{1,k}$ stands for the distance of the kth user to the first cell base station (cell of interest). β_k, τ_k, and η_k are, respectively, the gain, delay and phase of the kth signal at the receiver. The gain β_k is an independent Rayleigh random variable with parameter $\rho = \rho_k = E(\beta_k^2)/2$ for all k, while the delay τ_k, also independent for each signal, has a uniform distribution in [0, T_b]. Further, we assume that the phase η_k is an independent random variable, uniformly distributed in [0, 2π].

It is assumed that in the cellular system, there are C cells, each of which contains K active users and one base station. Therefore, there are CK active users for the entire cellular system. Ignoring white noise, the received signal is

$$r(t)=\sqrt{2P}\sum_{k=1}^{CK}\sqrt{\varepsilon(\gamma,c_k,k)}\beta_k a_k(t-\tau_k)b_k(t-\tau_k)\cos(2\pi f_0 t+\phi_k) \quad (3)$$

where $\phi_k=\theta_k+\eta_k-2\pi f_0\tau_k$, and c_k denotes the cell in which the kth user is located; the users are numbered such that c_k is the integer portion of $1+(k-1)/K$, $c_k=1,\cdots,C$. The first cell (c_k=1) is defined as the cell of interest, and P and $\varepsilon(\gamma,c_k,k)$ are defined as $P=P_k/(d_{c_k,k})^\gamma$ =constant and $\varepsilon(\gamma,c_k,k)=(d_{c_k,k}/d_{1,k})^\gamma$, respectively, where $d_{c_k,k}$ is the distance of the kth mobile user to its own base station (c_kth cell). The fact that P is taken to be a constant implies that each base station provides adaptive power control to all K users of its own cell so that all received signals from its cell have the same power.

Assuming the first user (k=1) of the first cell (c_k=1) is the reference user ($\tau_i=\phi_i=0$), the despreader output at a receiver is given by

$$\xi=\int_0^{T_b}r(t)\cdot 2a_1(t)\cos(2\pi f_0 t)dt=D+\sum_{k=2}^{K}I_k+\sum_{k=K+1}^{CK}\sqrt{\varepsilon(\gamma,c_k,k)}I_k \quad (4)$$

where a_1(t) is the code sequence of the first user and f_0 is the coherent carrier frequency, respectively. D is the desired signal term of the reference user. Given β_i, the conditional useful signal power is equal to $S(\beta_i)=2P\beta_i^2T_b^2$. I_k is the multiple access interference from the kth user and its variance equals $\sigma_0^2=4P\rho T_b^2/(3N)$. $\sum_{k=2}^{K}I_k$ and $\sum_{k=K+1}^{CK}\sqrt{\varepsilon(\gamma,c_k,k)}I_k$ are the multiple access interference terms from in-cell and all adjacent cells, respectively. Therefore, the variance of the in-cell interference is equal to $\sigma_1^2=(K-1)\sigma_0^2$, whereas the variance of the total adjacent-cell interference is given by

$$\sigma_2^2=\sigma_0^2\sum_{k=K+1}^{CK}E[\varepsilon(\gamma,c_k,k)]$$
$$=\sigma_0^2K\sum_{c=2}^{C}\varepsilon(\gamma,c)=\sigma_0^2K\zeta(\gamma)\approx\sigma_1^2\zeta(\gamma),$$
$$K>>1, \quad (5)$$

where $\varepsilon(\gamma,c)$ stands for the average of $\varepsilon(\gamma,c_k,k)$ over the area of the c_kth cell and $\zeta(\gamma)=\sum_{c=2}^{C}\varepsilon(\gamma,c)$, respectively. Note that the variance of the total adjacent-cell interference is $\zeta(\gamma)$ times as much as the variance of the in-cell interference. Furthermore, A hexagonal cell is approximated with a circular cell of equal area for simple calculation of $\varepsilon(\gamma,c)$, as in [3].

Assuming the sum of all multiple access interference terms is Gaussian, as in [1], the bit error rate is given by $P_e=\frac{1}{2}(1-\sqrt{\frac{R}{1+R}})$, where R denotes the ratio of the average signal to interference, given by

$$R\approx(3N/2K)/[1+\zeta(\gamma)]. \quad (6)$$

Table 1 illustrates the BER of the cellular CDMA system as a function of the propagation loss exponent, γ (γ=2,3,4), for a single layer, two layers and three layers of cells, respectively. Note that in a hexagonal cellular model, the numbers of cells are 6, 12, 18, for the first layer, second layer and third layer, respectively. Therefore, the number of the total adjacent cells are C=6, 18, 36, for accounting for one layer, two layers and three layers, respectively. It is clear from this table that when $\gamma=2$, the BER computed by accounting for only a single layer of cells is too optimistic; alternately, if $\gamma = 4$, the difference in BER performance between accounting for only a single layer and accounting for more layers is insignificant. Therefore, in conventional cellular radio, where the propagation path loss exponent is around 4, considering a single layer of cells is reasonable. However, in microcellular radio, where the propagation path loss exponent is shown in [1] to be between 2 and 3, it is necessary to consider more layers, for example, three layers.

III. CONCLUSIONS

The bit error rate (BER) performance of the microcellular CDMA system increases as the propagation loss exponent increases. More layers of cells should be considered in order precisely to evaluate the performance of a microcellular CDMA system.

References:

[1] T. S. Rappaport and L. B. Milstein, "Effects of radio propagation path loss on DS-CDMA cellular frequency reuse efficiency for the reverse channel," *IEEE* Transactions on Vehicular Technology, vol. VT-41, pp. 231-242, Aug. 1992.

[2] G. R. Cooper and R. W. Nettleton, "A spread-spectrum technique for high-capacity mobile communications," *IEEE* Trans. Vehicular Tech., vol. VT-27, PP. 264-275, Nov. 1978.

[3] J. Wang and L. B. Milstein, "Approximate interference of a microcellular spread spectrum system," *Electronics Letters*, vol. 31, pp. 1782-1783, no. 20, 1995.

TABLE I

Bit error rate of a microcellular CDMA system as a function of propagation exponent (γ) for accounting for various layers of cells (K=10 and N=127)

γ	One Layer	Two Layers	Three Layers	
2	0.7	0.88	1	($\times 4.1\times10^{-2}$)
3	0.89	0.96	1	($\times 2.6\times10^{-2}$)
4	0.96	0.99	1	($\times 2.1\times10^{-2}$)