On the Code Selection of a Multicode DS/CDMA System for a High Data Rate Transmission

Jin Young Kim

Central Research and Development Center
SK Telecom
9-1, Sunae-dong, Pundang-gu, Sungnam City
Kyunggi-do 463-020, Korea

Abstract— **The effect of code selection for a multicode DS/CDMA system is evaluated for a high data rate transmission. The performance is evaluated in terms of bit error and outage probabilities. The multipath fading channel is modeled as a Nakagami-*m* distribution which has been known to be appropriate to model the multipath fading in urban as well as indoor channels. From simulation results, it is shown that the concatenated sequence of Walsh code and Gold sequence is most promising among many code selections. The considerations in this paper can be applied to the next-generation mobile communication systems such as IMT-2000 which requires high bit rate transmissions.**

I. INTRODUCTION

In the next-generation mobile communication system, multirate services require high transmission rates up to several Mbps [1-3]. However, the ability of high transmission is severely restricted by the propagation characteristics in a multipath fading channel [4,5]. To mitigate the delay spread impairments in a multipath fading channel, *multicode* DS/CDMA (direct-sequence/code-division- multiple-access) technique has been proposed [6,7]. In a multicode DS/CDMA system, data streams with different transmission rates is easily integrated into a unified architecture, with all the transmissions over the radio channel occupying the same bandwidth and having the same processing gain [7].

In many CDMA applications, more than one spread-spectrum (SS) code (or sequence, termed interchangeably) is required to operate simultaneously in a multiple access environment. The distinguishiablity of different SS signals by receivers depends on many factors including SS codes, modulation formats, and the receiver's detector structure, etc.. The main goal to design of SS code is to minimize of the absolute value of crosscorrelation between codes. The codes with minimum crosscorrelation is known to achieve the optimun network (system) performance in the DS/CDMA applications [8].

It is known that the performance of a multicode DS/CDMA system heavily depends on the code selection. Therefore, the code selection should be critically considered in the design of a multicode DS/CDMA system. The crosscorrelation value between codes has major impacts on the performance of a multicode DS/CDMA system. Typically, the following types of codes can be chosen: 1) PN code such as m-sequence, Gold sequence, and Kasami sequence, etc., 2) orthogonal code such as Walsh code, and 3) combination (or concatenation) of PN code and orthogonal code. The PN sequence have been widely used in a DS/CDMA system [8-10]. In a multicode DS/CDMA system, the low-rate data streams are synchronously transmitted, so orthogonal codes can also be applied to a multicode DS/CDMA system as long as the orthogonal codes are synchronized. For the orthogonal codes, maintaining a zero-crosscorrelation between codes is not easy in a multipath fading channel due to multipath delay spread. As an alternative of the orthogonal codes, the combination of PN code and orthogonal code has been considered because it is expected to be more robust to the multipath fading than the orthogonal code only [9,10].

In this paper, the effect of code selection on performance of a multicode DS/CDMA system is evaluated through simulation in a multipath fading channel. The performance is evaluated in terms of bit error and outage probabilities. The multipath fading channel is modeled as a Nakagami-*m* distribution which has been known to be appropriate to model the multipath fading in urban as well as indoor channels.

The organization of the paper is as follows: In Section II, system and channel models are described In Section III, bit error and outage probabilities of a multicode DS/CDMA system are analyzed. In Section IV, simulation results are presented and, finally, the conclusions are drawn in Section V.

II. SYSTEM MODEL

A. System Description

The block diagram of a multicode DS/CDMA system is shown in Fig. 1. (a) and (b). A high bit rate stream is first split into M parallel low rate data streams. The M parallel data streams are spread and added together. The spreading codes should be orthogonal or near-orthogonal over a symbol interval in a parallel branch to reduce the intercode interference. For variable rate services, the number of channels M can vary during the call while processing gain on each channel is fixed.

B. Channel Model

The multipath rays arise from scattering, reflection, or diffraction of the radiated energy due to objects that lie in the environment. Apart from amplitude attenuation, multipath propagation can also cause spreading of signal in time, frequency, and space. A Rayleigh fading model has been used to characterize the fading signal envelope in small geographical areas or short term fading and sometimes does not account well for large scale variations in the signal envelope encountered when wide geographical areas are involved [5]. A generalized fading model is Nakagami-m distribution which has been shown to be appropriate to model the multipath fading in urban as well as indoor channels [11,12]. The probability distribution function ($p.d.f.$) of the lth path for a Nakagami-m distribution is given by

$$p_{\beta_l}(\beta) = 2\left(\frac{m_l}{\Omega_l}\right)\frac{\beta^{2m_l-1}}{\Gamma(m_l)}exp\left(-\frac{m_l}{\Omega_l}\beta^2\right), \quad \beta \geq 0, \qquad (1)$$

where $\Omega_l = E[\beta_l^2]$ and $\Gamma(m)$ is a Gamma function. The fading index m characterizes the severity of the fading. It is known that $m = 1$ corresponds to Rayleigh fading (purely diffusive scattering), $m \to \infty$ corresponds to the nonfading condition, and $m = 0.5$ (one-sided Gaussian fading) corresponds to the worst case fading condition. From the tapped-delay line model for a multipath fading channel, the lowpass equivalent impulse response of the multipath fading channel is given by

$$h_k(t) = \sum_{l=1}^{L_k} \beta_{k,l}\delta(t - \tau_{k,l})e^{j\alpha_{k,l}}, \qquad (2)$$

where L_k is the number of multipaths, $\beta_{k,l}$ is Nakagami-m distributed path strength, $\alpha_{k,l}$ is the phase uniformly distributed $[0, 2\pi]$, and $\tau_{k,l}$ is path delay uniformly distributed over the duration of channel delay spread.

III. PERFORMANCE ANALYSIS

In the performance analysis, the followings are assumed: 1) uniform user distribution of K users in a cell, 2) the number of multipath components $L_k = 2$ $(1 \leq k \leq K)$ for all the users, 3) perfect power control ($P_k = P$, $1 \leq k \leq K$), and 4) perfect code synchronization.

A. Bit Error Probability

The mth data stream is given by

$$s_m(t) = \sqrt{2P_m}\,d_m(t)c_m(t)\cos[j(\omega_c t + \psi_m)], \qquad (3)$$

where P_m is transmission power, $d_m(t)$ is data sequence with bit duration T_b, $c_m(t)$ is spreading sequence with chip duration T_c, $\tau_m(t)$ is propagation delay, ω_c is carrier frequency, and ψ_m is carrier phase of the mth data stream, respectively. Then, the transmitted signal is given by

$$x(t) = \sum_{m=1}^{M} s_m(t), \qquad (4)$$

With K active users and reference user (user 1), the received signal is given by

$$\begin{aligned} r(t) \;=\; & \sqrt{\frac{P}{2}}\sum_{m=1}^{M}\beta_{1,1}^{m}c_1^m(t-\tau_{1,1})d_1(t-\tau_{1,1}) \\ & + \sqrt{\frac{P}{2}}\sum_{j=1}^{L-1}\sum_{m=1}^{M}\beta_{j,1}^{m}c_1^m(t-\tau_{j,1})d_1(t-\tau_{j,l})\exp(j\phi_{j,1}^{m}) \\ & + \sqrt{\frac{P}{2}}\sum_{k=1}^{K-1}\sum_{j=1}^{L}\sum_{m=1}^{M}\beta_{j,k}^{m}c_k^m(t-\tau_{j,1})d_1(t-\tau_{j,k}) \\ & \cdot \exp(j\phi_{j,k}^{m}) + n(t), \qquad (5) \end{aligned}$$

where $\tau_{j,k}$ and $\phi_{j,k}^{m}$ are propagation delay and phase, respectively, for $1 \leq k \leq K$, $1 \leq j \leq L$, $1 \leq m \leq M$, and $n(t)$ is the AWGN component with zero mean, variance σ_n^2, and power spectral density N_0.

The output of the RAKE receiver consists of the following four parts: 1) desired user's signal component, 2) self interference component due to multipath (I_1), 3) MAI component due to other interfering users (I_2), and 4) background noise component. In the analysis of bit error probability, the Gaussian approximation is employed because it provides sufficient accuracy in case of a large number of users and a large processing gain. Then, the variance of total interferences is given by

$$\sigma_t^2 = \sigma_{I_1}^2 + \sigma_{I_2}^2 + \sigma_n^2 \qquad (6)$$

Under perfect power control, the total variance is given by

$$\sigma_t^2 = \frac{MN_0}{T_b} + \frac{PM}{2}(K\sum_{j=1}^{L}E[\beta_{j,1}^2] + (K-1)E[\beta_{1,1}^2]). \qquad (7)$$

Then, the bit error probability is obtained as

$$P_b = \frac{1}{2}erfc\left(\sqrt{\frac{\frac{P}{2}(\sum_{m=1}^{M}\beta_{1,1}^{m})^2}{2\sigma_t}}\right), \qquad (8)$$

where $erfc(x) = \frac{2}{\sqrt{\pi}}\int_x^\infty e^{-t^2}dt$.

B. Outage Probability

Outage probability is an important measure in the design of cellular and mobile communication systems to operate in a fading environment with multiple interferers. As an indication of a minimum requirement on the grade of service, outage probability represents the probability of unsatisfactory reception over the intended coverage area. The dominant interference in a mobile cellular system is cochannel interference which determines the degree of frequency reuse and spectrum efficiency available in a given system [13]. The signal outage experienced by a mobile user results in poor quality of service, particularly near the cell boundary. An outage can be defined in terms of bit error rate, SINR, or a combination of SINR and a minimum signal power constraint.

Outage probability can be used as a statistical measure which describes the probability of failing to achieve adequate reception of a signal at a particular location. To achieve adequate reception, the short-term desired signal must be simultaneously greater than some minimum signal powers by a margin known as intereference protection ratio. In this paper, the outage probability is defined as the probability that the SINR drops below a minimum threshold. Then, outage probability is given by

$$Prob(BER > BER_t) = Prob(\sigma^2 < \sigma_t^2), \qquad (9)$$

where BER is bit error rate, BER_t is threshold BER for the acceptable signal quality, σ^2 is SNR, and σ_t^2 is threshold SNR corresponding to BER_t.

IV. SIMULATION RESULTS

For the simulation examples, carrier frequency = 2 GHz, the number of parallel data streams M = 16, the data rate = 128kbps, processing gain = 64, chip rate = 8.192 Mcps (64*128 kbps), bandwidth = 10MHz, data rate of each parallel branch = 8kbps (=128kbps/16), Walsh code length = 64, short code length (of m-sequence, Gold, and Kamami sequence) = $2^{18} - 1$ cps, SNR = 10dB, and Doppler frequency = 30Hz are assumed.

In Fig. 2, bit error probability *vs.* the number of users is shown for the different code selection and fading index m=10. The bit error probability is compared for the three concatenated sequences: 1) Walsh code and m-sequence, 2) Walsh code and Kasami sequence, and 3) Walsh code and Gold sequence. The Gold sequence and Kasami sequence are constructed from the preferred pair of m-sequence and a composite of a preferred m-sequence with its properly decimated version, respectively. It is shown that the concatenated sequence of Walsh code and Gold sequence achieves the best performance among three concatenated code selections for both Rayleigh and Rician fading channels. The performance difference among them becomes a little bit larger as the number of users increases because the cross-correlation effect becomes more significant for the larger number of interfering users.

In Fig. 3, bit error probability *vs.* the number of users in a cell is shown for the different fading index and Walsh+Gold sequence. It is shown that the larger m produces better BER performance because the m larger than 1 represents milder fading conditions resulting in a Rician fading with specular component.

In Fig. 4, outage probability *vs.* the number of users in a cell is shown for the different code selection and fading index m=10. Outage performance is shown to be better for the Walsh+Gold sequence than for the other cases. When we set the outage probability threshold as 10^{-2} for nominal operation, 23 users and 16 users can be accommodated for the Walsh+Gold sequence and Walsh+m-sequence, respectively. This represents the capacity increase of the system by employing Walsh+Gold sequence.

In Fig. 5, outage probability *vs.* the number of users in a cell is shown for the different fading index and Walsh+Gold sequence. Similarly as the case of bit error probability, the larger m produces better outage performance due to less adverse fading conditions.

V. CONCLUSIONS

The impact of code selection on performance of a multicode DS/CDMA system was evaluated through simulation in a Nakagami-m fading channel. The performance was evaluated in terms of bit error and outage probabilities. From the simulation results, it was shown that the concatenated sequence of Walsh code and Gold sequence achieves the better BER and outage performance among three concatenated code selections for both Rayleigh and Rician fading channels. The performance results of a multicode system seem to be rather optimistic in a practical implementation point-of-view because the drawbacks of the multicode system has not been considered. The performance of the multicode CDMA system can be improved by channel coding and other techniques in the receiver. The considerations in this paper can be applied to the next-generation mobile communication systems such as IMT-2000 which requires high bit rate transmissions.

REFERENCES

[1] A. Baier, U. C. Fiebig, W. Granzow, W. Koch, P. Teder, and J. Thielecke, "Design study for a CDMA-based third-generation mobile radio system," *IEEE J. Select. Areas Commun.*, vol. 12, no. 4, pp. 733-743, May 1994.

[2] D. L. Schilling, "Broadband spread spectrum multiple access for personal cellular communications," in *Proc. of the IEEE VTC'93*, pp. 819-822, May 1993.

[3] D. C. Cox, "Wireless network access for wireless communications," *IEEE Commun. Mag.*, vol. 30, no. 12, pp. 96-115, Dec. 1992.

[4] R. Prasad, *CDMA for Wireless Personal Communications*, Artech House Publishers, 1996.

[5] G. L. Stuber, *Principles of Mobile Communications*, Kluwer Academic Publishers, 1996.

[6] C. L. I and R. D. Gitlin, "Multi-code CDMA wireless personal communications networks," in *Proc. of IEEE ICC'95*, pp. 1060-1064, Seattle, WA, U.S.A., June 1995.

[7] K. Ben Letaif, J. C-I Chuang, and R. D. Murch, "Multicode high-speed transmission for wireless personal communications," in *Proc. of the IEEE GLOBECOM'95*, pp. 1835-1839, Singapore, Nov. 1995.

[8] D. V. Sarwate and M. B. Pursley, "Crosscorrelation properties of psedorandom and related sequences," *Proc. of IEEE*, vol. 68, pp. 593-619, May 1980.

[9] F. Adachi, M. Sawahashi, and K. Okawa, "Tree-structured generation of orthogonal spreading codes with different length for forward link of DS-CDMA mobile radio," *Electron. Lett.*, vol. 33, no. 1, pp. 27-28, Jan. 1997.

[10] J. Y. Kim, "Performance of a multicode DS/CDMA system with spatial filtering in a Nakagami fading channel," *Accepted for publication to IEICE Transactions on Fundamentals.*

[11] M. Nakagami, "The m-distribution - A general formula of intensity distribution of fading," in *Statistical Methods in Radio Wave Propagation*, W. C. Hoffman, Ed., New York: Pergamon, 1960.

[12] G. P. Efthymoglou, V. A. Aalo, and H. Helmken, "Performance analysis of coherent DS-CDMA systems in a Nakagami fading channel with arbitrary parameters," *IEEE Trans. Veh. Technol.*, vol. 46, no. 2, pp. 289-297, May 1997.

[13] A. Abu-Dayya and N. C. Beaulieu, "Outage probabilities of cellular mobile systems with multiple Nakagami interferers," *IEEE Trans. Veh. Technol.*, vol. 40, no. 4, pp. 757-767, Nov. 1991.

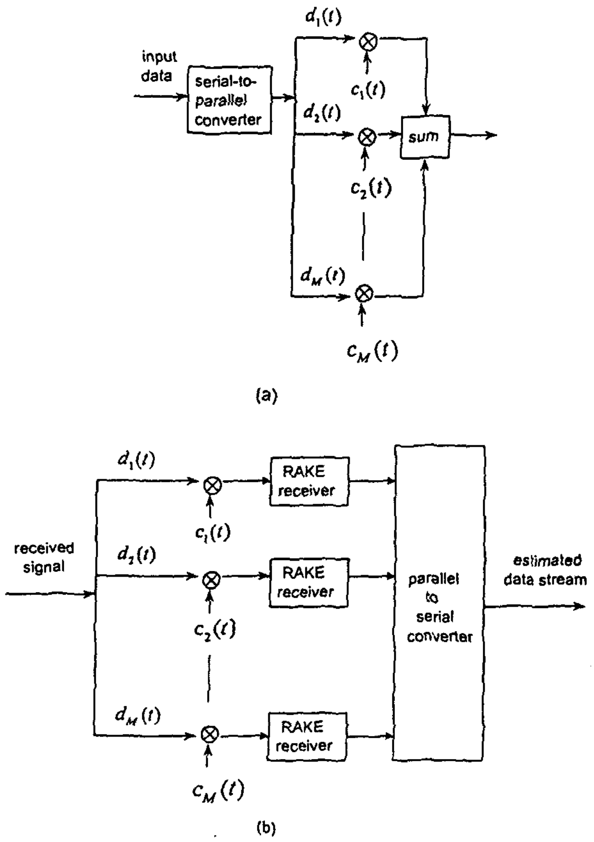

Fig. 1. Multicode DS/CDMA system. (a) Transmitter. (b) Receiver.

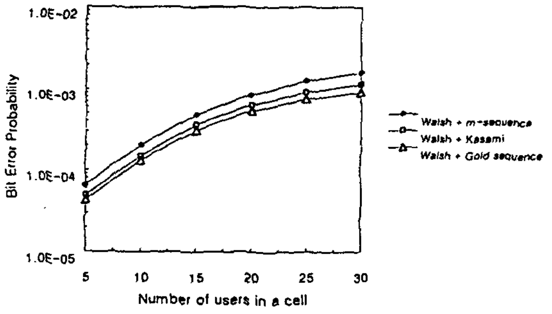

Fig. 2. Bit error probability vs. the number of users for the different code selection.

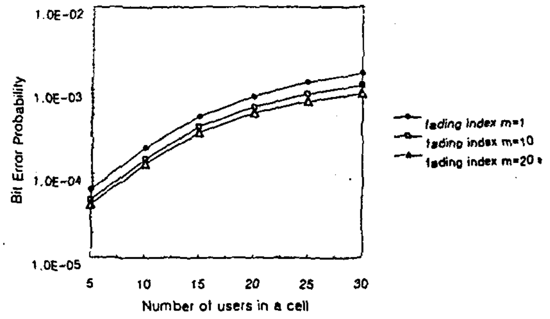

Fig. 3. Bit error probability vs. the number of users for the different fading index.

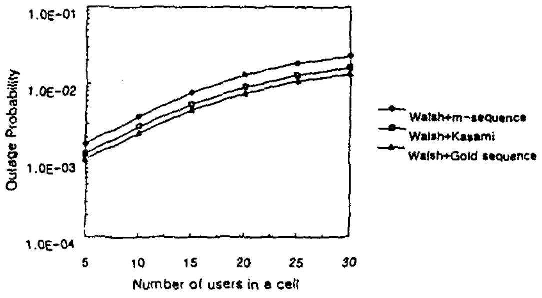

Fig. 4. Outage probability vs. the number of users for the different code selection.

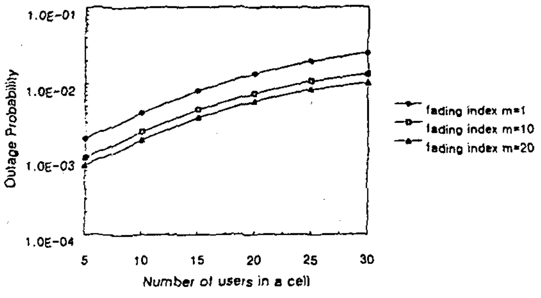

Fig. 5. Outage probability vs. the number of users for the different fading index.