Performance of a Multicode DS/CDMA Packet Radio Network with Adaptive Antenna Array

Jin Young Kim, Ph. D. and Sang Yun Lee, Ph. D.

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

ABSTRACT

In this paper, performance of multicode DS/CDMA packet radio network with adaptive antenna array is analyzed and simulated in a multipath Rayleigh fading channel. The network performance is evaluated in terms of packet throughput. From the simulation results, it is confirmed that the adaptive antenna array is very effective in improving the packet throughput performance of the multicode DS/CDMA packet radio network. The results of this paper can be applied to design of IMT-2000 or future-generation mobile communication systems.

I. INTRODUCTION

Future wireless communication systems including IMT-2000 are required to support multimedia traffic with different quality of services (QoS's) [1,2]. DS/CDMA (direct sequence/code division multiple access) has been known to be a promising multiple access technique for multirate data transmission [1]. To support multirate traffic, there have been many proposed schemes such as multi-modulation (MM), multicarrier (MC), multicode, variable spreading gain (VSG) CDMA, etc [3-6]. In this paper, we adopt the multicode CDMA system as a multirate transmission scheme because it has some advantageous features compared to the other methods. In a multicode CDMA system, the traffic streams with different transmission rates can be easily integrated into unified framework just by adjusting the number of codes assigned to the high data rate user. It is generally known that the MM/CDMA system suffers from performance degradation for the high rate users while in the VSG/CDMA scheme, the high rate users are likely to be sensitive to external interference due to low spreading gain [3].

In the recent past, adaptive antenna array has attracted considerable interest in the mobile communication community [7,8]. The adaptive antenna array is known to have potential to provide designers with an extra dimension of SDMA (space-division-multiple-access) along with FDMA, TDMA, and CDMA in solving the problems related with the realization of the mobile communication system [9,10]. It is widely accepted that an adaptive antenna array will offer potential solutions to a number of the key requirements since it provides many promising features such as high capacity, high spectrum efficiency, and more degrees of freedom to adjust cell coverage characteristics, leading to more efficient use of radio resources [11-13].

In a conventional single code DS/CDMA system, each user transmits its signal only one CDMA channel with a processing gain which is inversely proportional to the data rate. However, in a multicode DS/CDMA system, a high-data rate stream is first split into several fixed low-data rate streams. The multiple low rate streams are spread by different short spreading codes with the same chip rate, and then are combined together. It is required in the multicode DS/CDMA system that the multiple short spreading codes are orthogonal over one bit duration to reduce intercode interference.

The previous approaches on adaptive antenna array have focused on the performance improvement of bit or symbol level error performance through spatial filtering [14]. Very recently, it was demonstrated that packet throughput of the FH/SSMA packet radio network can be improved by employing adaptive antenna array [15]. However, there has not yet been any approach to improve the performance of a multicode DS/CDMA packet radio network by employing adaptive antenna array.

In this paper, performance of multicode DS/CDMA packet radio network with adaptive antenna array is analyzed and simulated in a multipath Rayleigh fading channel. The network performance is evaluated in terms of packet throughput. The packet radio network is modeled as a slotted ALOHA where the packet is transmitted only at the beginning of each slot [16].

The rest of the paper is organized as follows: In Section II, transmitter and receiver models for a multicode DS/CDMA system are described. In Section III, packet model and adaptive antenna array algorithm are described. In Section IV, simulation results are presented, and conclusions are drawn in Section V.

II. SYSTEM DESCRIPTION

II. 1. Multicode DS/CDMA System

The block diagram of a multicode DS/CDMA system with adaptive antenna array is shown in Fig. 1. (a) to (c). The basic principle of adaptive antenna array is that the desired beam can be formed by adding together by weighting the signals and adjusting their amplitudes and phases. The output of beamformer is RAKE processed by combining multipath components. Then, the decision on the transmitted data is made.

In a multicode transmission scheme, a high rate data stream is first split into M parallel low rate data streams. The M parallel data streams are spread by different codes and added together. The spreading a parallel branch to reduce the interco-de interference. For variable service, the number of active channels M can vary during the call while processing gain on each channel is fixed.

In the adaptive antenna array as shown in Fig. 1. (c), the received signal passes through an antenna array and the output of the antenna array is processed at the spatial filter which is controlled by an adaptive processor. The adaptive processor is operated from the difference of the delayed array output and the reference signal. The signals from the receiving antennas are combined to mitigate the MAI using adaptive antenna array. The tap weights are adaptively updated to form a beam with the maximum gain to the desired user and a beam with nulls to the interfering users. A simple linear antenna array with identical elements is considered.

II. 2. Channel Model

The lowpass equivalent impulse response of channel model is given by

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

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

III. SYSTEM MODELING

In the performance analysis, the followings are assumed: 1) users are uniformly distributed in a cell, 2) cell pattern is hexagonal, 3) each user transmits one packet, and 4) slot synchronization for the slotted mode operation is perfect.

III. 1. Packet Model

The multicode CDMA system under consideration has fixed bandwidth. We classify all the users in the system into two categories: class I (low rate user) and class II (high rate user). Both class I and class II traffics are transmitted in a packetized form. The class I user has basic data rate. The class II user is assumed to have data rate which is an integer multiple of the basic data rate. The class I traffic (typically, voice) requires real-time delivery while it is tolerant to transmission errors. On the other than, the class II (typically, data or image) traffic requires very low packet error probability while it does not require the real-time transmission, which leads to the possibility of queueing of data packet. The packet arrival process from the class II traffic is modeled as Poisson process.

For the slotted mode operation, the time axis is divided into slots, and slot duration (T_s) is one packet duration (T_p). The input data stream is split into M substreams, and each substream has a duration of T_p and a length L_p. We call a packet of substream *mini packet*. The mini packet in a substream is multiplied by orthogonal spreading sequence which is chosen out of a set of M orthogonal spreading sequences. By doing this, we can avoid self-interference with the other mini packets for the same user. As shown in Fig. 2, in a slot duration, the M mini packets are transmitted for the class II traffic.

III. 2. Adaptive Algorithm of Antenna Array

The selection of adaptive algorithm for adaptive weights is very important in that it determines both convergence rate and hardware complexity required to implement the algorithm. LMS (least-mean-square) algorithm has widely been used for tap coefficient adaptations of an adaptive processor in an antenna array, but it causes signal acquisition and tracking problems due to its slow convergence in a multipath fading channel. DMI (direct matrix inversion) algorithm has been proposed due to its fast convergence property, however, it is too computationally complex and causes numerical instability. CMA (constant modulus algorithm) has been considered in a TDMA mobile cellular system, but it is not suitable for a CDMA mobile cellular system because of power control. In this paper, RLS algorithm is adopted because it achieves faster convergence than LMS algorithm and is less computationally complex than DMI algorithm. The RLS algorithm is employed to find a weight vector $\mathbf{W}$ such that the array elements can steer a beam in a desired direction.

The iterative relations for weight updating of the RLS algorithm is given by

$$\hat{\mathbf{w}}(n) = \hat{\mathbf{w}}(n-1) + \mathbf{q}(n)[d^*(n) - \hat{\mathbf{w}}^H(n-1)\mathbf{x}(n)], \qquad (2)$$

where $\mathbf{q}(n)$ is the gain factor and $d^*(n)$ is the reference desired signal. The gain factor $\mathbf{q}(n)$ is given by

$$\mathbf{q}(n) = \frac{\mu^{-1}\mathbf{R}^{-1}(n-1)\mathbf{x}(n)}{1 + \mu^{-1}\mathbf{x}^H(n)\mathbf{R}^{-1}(n-1)\mathbf{x}(n)}, \qquad (3)$$

where $\mu(0 \le \mu \le 1)$ is a forgetting factor, which allows the data in the distant past to be forgotten, and $\mathbf{R}^{-1}$ is the inverse of covariance matrix.

IV. SIMULATION RESULTS

In this section, we present some simulation results. For the simulation examples, carrier frequency = 2GHz, chip rate = 4.096 cps (chips/second), basic data rate = 8kbps, the forgetting factor of RLS algorithm μ = 0.95, SNR = 10dB, length of mini packet = 512 bits, Doppler frequency = 30Hz, two-ray multipath fading channel, and standard deviation of shadowing = 8 dB (urban environment) are assumed.

The uniform linear array (ULA) of omnidirectional sensors with half wavelength antenna spacing is simulated. Antenna spacing larger than half wavelength improves the spatial resolution of the array, but it forms a grating lobes (the secondary maxima). The RLS algorithm can adapt the tap weights of each spatial filter to the Wiener filter solution quickly by using the matrix inversion lemma.

In Fig. 3, packet throughput vs. offered load is shown for the number of parallel data streams M = 8, the number of class I users $K_1 = 3$, and processing gain = 64. The offered load represents the average number of generated packets in one slot duration. It is shown that the packet throughput is significantly increased by employing the adaptive antenna array. This enhancement mainly comes from the array gain on the desired user (or desired packet).

In Fig. 4, we introduce throughput enhancement factor (TEF) defined by ratio of packet throughput with and without 8-element adaptive antenna array. The simulation example is shown for the varying the number of code channels with $K_1 = 3$. It is shown that the degree of throughput enhancement increases with the number of code channels.

V. CONCLUSIONS

The packet throughput was simulated for the multicode DS/CDMA packet radio network to support multirate traffic in a multipath Rayleigh fading channel. The traffic was classified into two classes: low and high rate traffics. It is shown that the packet throughput enhancement becomes more significant with the number of array elements of adaptive antenna array. The results of this paper can be applied to design of IMT-2000 or future-generation mobile communication systems.

REFERENCE

[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, 1994.

[2] K. Phalavan and A. H. Levesque, "Wireless data communications," *Proc. IEEE*, vol. 82, no. 9, pp. 1398-1430, Sept. 1994.

[3] T. Ottosson and A. Svensson, "On schemes for multirate support in DS-CDMA systems," *Wireless Personal Communications*, vol. 6, no. 3, pp. 265-287, Mar. 1998.

[4] J. Y. Kim and J. H. Lee, "Multicarrier transmission technique for a DS/CDMA system," *in Proc. of the 1997 Korea-China Joint Symposium on Wireless Communication Technologies*, pp. 27-32, Seoul, Korea, Nov. 1997.

[5] I. Chih-Lin and R. D. Gitlin, "Multi-code CDMA wireless personal communication networks," *in Proc. of the IEEE ICC'95*, pp. 1060-1064, June 1995.

[6] M. Soroushnejad and E. Geraniotis, "Multi-access strategies for an integrated voice/data packet radio network," *IEEE Trans. Commun.*, vol. 43, no. 2/3/4, pp. 934-945, Feb./Mar./Apr., 1995.

[7] J. Litva and T. K. Lo, *Digital Beamforming in Wireless Communication*, Artech House, 1996.

[8] D. H. Johnson and D. E. Dudgeon, *Array signal processing: Concepts and Techniques*, Prentice-Hall, 1993.

[9] J. Y. Kim and J. H. Lee, "Performance of a combined SDMA/CDMA system in a Nakagami fading channel," *in Proc. of the 1997 CDMA International Conference (CIC '97), pp. 279-282, Seoul, Korea,* Oct. 1997.

[10] G. Tsoulos, M. A. Beach and S. C. Swales, "Adaptive antennas for third generation DS-CDMA cellular systems," *in Proc. of the IEEE VTC '95*, pp. 45-49, Chicago, IL, U.S.A, Aug. 1995.

[11] A. F. Naguib, A. Paulraj, and T. Kailath, "Capacity improvement with base-station antenna arrays in cellular CDMA," *IEEE Trans. Veh. Technol.* Vol. 43, no. 3, pp. 691-698, Aug. 1994.

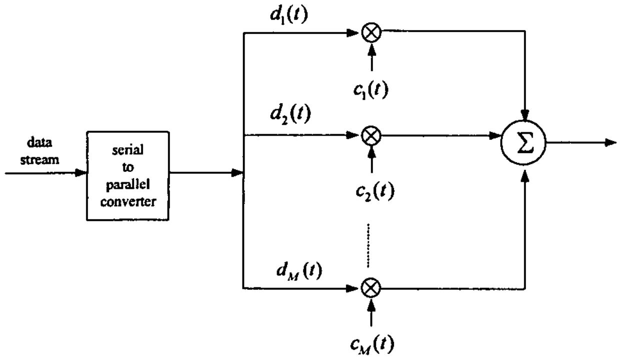
[12] J. Y. Kim and J. H. Lee, "Performance of a multicarrier DS/CDMA system with adaptive antenna array in a Nakagami fading channel," *in Proc. of the IEEE PIMRC '98*, pp. 759-763, Boston, MA, U.S.A., Sept. 1998.

[13] J. Y. Kim, "Performance of a multicarrier DS/ CDMA system with adaptive antenna array," *Ph. D. Dissertation*, Seoul National University, Seoul, Korea, 1998.

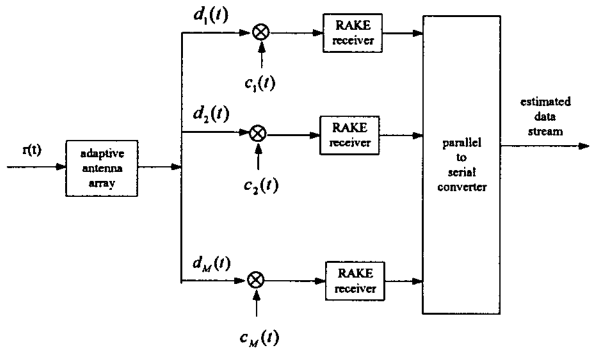
[14] J. Y. Kim and J. H. Lee, "Performance of a multicode CDMA system with adaptive antenna array," *in Proc. of the IEEE MoMuC '97*, pp. 538-543, *Seoul, Korea,* Sept. 1997.

[15] J. Y. Kim, "Throughput enhancement of a frequency-hopping spread-spectrum network with adaptive antenna array and packet combining," *IEE Electronics Letters*, vol. 35, no. 4, pp. 280-281, Feb. 1999.

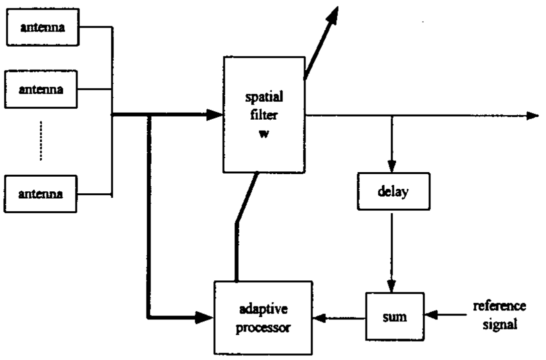
[16] D. Makrakis and K. M. S. Murthy, "Spread slotted ALOHA techniques for mobile and personal satellite communication systems," *IEEE. J. Select. Areas Commun.*, vol. 10, no. 6, pp. 985-1002, Aug. 1992.



(a) Transmitter model



(b) Receiver model



(c) Adaptive antenna array

Fig. 1. Multicode DS/CDMA system with adaptive antenna array.

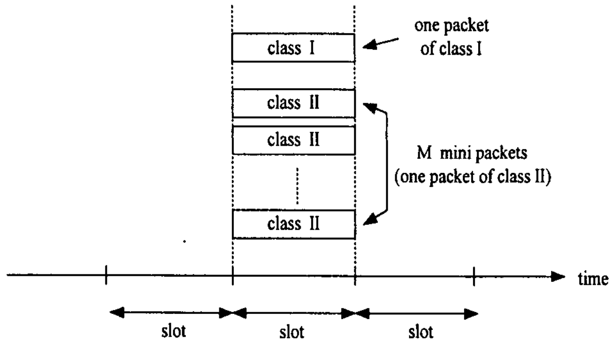


Fig. 2. Schematic diagram of packet transmission scheme for slotted mode operation.

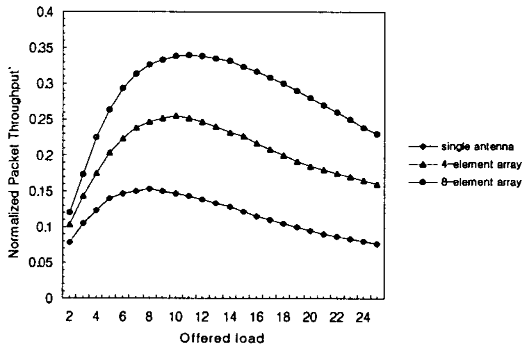


Fig. 3. Packet throughput vs. offered load.

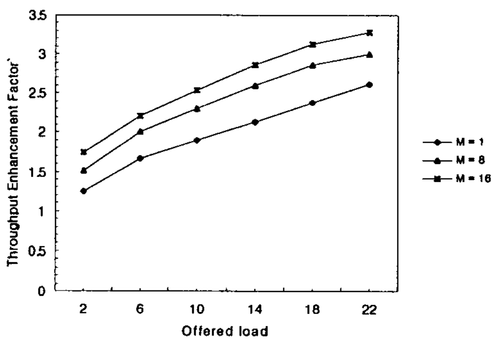


Fig. 4. Throughput enahncement factor vs. offered load.