Capacity Enhancement through Adaptive Antenna Array for a Multicarrier DS/CDMA System

Jin Young Kim

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

ABSTRACT

In this paper, capacity of a multicarrier DS/CDMA system is analyzed and simulated in a Nakagami fading channel. It is confirmed that the adaptive antenna array is a very efficient solution to enhance system capacity of a multicarrier DS/CDMA system. The results in this paper can be applicable to receiver design for the third and fourth mobile communication systems.

I . INTRODUCTION

Capacity of a DS/CDMA (direct-sequence/code division multiple access) system is typically defined as the maximum number of users which the system can accommodate [1]. The capacity of a CDMA system is determined by call admission policy which is used in each cell [2]. A typical call admission policy is to allow new calls into the cell until the total interference from other users exceeds a certain threshold level. Since the reverse link is the limiting link in terms of user capacity and the adaptive antenna array is installed in a base station, we focus our attentions to the reverse-link capacity.

Since a DS/CDMA system is interference-limited, when the number of active users exceeds a certain threshold, the system outage occurs [3]. In a DS/CDMA system, the number of users which each cell can support is limited by the total received interference at the base station and varies with time. The capacity is actually influenced by the users of the own cell and the users of neighboring cells. The received SIR to obtain a certain BER is a function of channel conditions.

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 [4,5]. The promising techniques such as multicarrier transmission and adaptive antenna array can be combined to achieve more improved performance compared with the conventional system [6,7]. When we combine these two techniques, we can make full use of the advantages of both techniques to improve the overall system performance. There have been some approaches on high data rate transmissions with adaptive antenna array

In this paper, we analyze and simulate the performance of a multicarrier DS/CDMA system to enhance the system capacity. It is assumed that the users' transmissions arrive with the same power at the base station by some adaptive power control algorithm (perfect power control). A linear antenna array with equispacing identical array elements and half wavelength antenna spacing is considered. We compare the system capacity for a single-carrier and a multicarrier DS/CDMA systems using the practical parameters in the real environment. The sectorization gain is not considered in this paper because we are interested only in a sector.

The rest of the paper is organized as follows: In Section II, the system and channel models are described. In Section III, the capacity is defined. In Section IV, some simulation results are presented, and finally, the conclusions are drawn in Section V.

II. SYSTEM MODEL

II. 1. System Description

In Fig. 1. (a), input data sequence with bit duration T_b is serial-to-parallel converted into M parallel streams, each of which has duration of $T_1 = MT_b$. Each stream feeds S parallel branches, each of which has the same data stream. In each of S branches, data sequence is multiplied by spreading sequence and is modulated by carrier. The output signals of MS branches are summed before transmission.

At the receiving side of the *kth* user as shown in Fig. 1. (b), the transmitted signal is first processed at the adaptive antenna array. The receiver of the *kth* user employs *MS* matched-filter (MF) detectors, each tuned and synchronized to one of the carriers. The output of the adaptive antenna array is despread by the

PN code and the despread output passes through from the first carrier processor to the *Mth* carrier processor. The data decision is made using the output of the each carrier processor, and the results of data decision are parallel-to-serial converted.

At 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 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.

II. 2. Channel Model

The *p.d.f.* of Nakagami fading channel for the *kth* user and the *lth* path is given by

$$f_{\beta_{k,l}}(\beta) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_{k,l}}\right)^m \beta_{k,l}^{2m-1}\exp(-\frac{m}{\Omega_{k,l}}\beta_{k,l}^2), for \quad \beta_{k,l} \geq 0, \quad m \geq \frac{1}{2} \tag{1}$$

where $\Gamma(m) = \int_0^\infty t^{m-1}e^{-t}dt \ (m > 0)$ is Gamma function, $E[\beta_{k,l}^2] = \Omega_{k,l}$, and m is a fading index of Nakagami fading channel representing the severity of fading. The fading index m given by $m = \Omega_{k,l}^2 / (E[(\beta_{k,l}^2 - \Omega_{k,l})^2])$ is assumed to be the same for all users and all paths.

From the tapped-delay-line (TDL) model for the multipath fading channel, the lowpass equivalent impulse response of channel model is given by

$$h_k(t) = \sum_{l=1}^{L_k} \beta_{k,l}\delta(t - lD)\exp(-j\alpha_{k,l}), \tag{2}$$

where L_k is the number of multipath for the kth user, $\beta_{k,l}$ is Nakagami-*m* distributed path strength, D_s is tap spacing of the TDL fading model, and $\alpha_{k,l}$ is the phase with uniform distribution in [0, 2π]. A multipath fading channel is characterized by its multipath intensity profile (MIP) which is the average power at the output of the channel as a function of path delay.

III. CAPACITY DEFINITION

When we estimate the system capacity (the maximum allowable number of users), the following factors affect the system capacity: 1) processing gain, 2) SNR, 3) voice activity factor, 4) sectorization gain, 5) propagation conditions such as fading and shadowing, and 6) blocking probability for voice calls. For example, the capacity of voice calls is usually determined according to Erlang-B formula. The capacity can be estimated with three constraints: 1) outage probability, 2) bit error probability, and 3) PN acquisition performance [8].

The capacity is defined as

$$C = K_{\max}, \text{ for } P_{out} < P_{out,ref}, \tag{3}$$

$$\approx \frac{W/R}{E_b/N_0} \cdot V_{af}, \text{ for } P_{out} < P_{out,ref}, \tag{4}$$

where $K_{\max}$ is the maximum number of users accommodated in the system, P_{out} is outage probability, $P_{out,ref}$ is reference outage probability, W is transmission bandwidth, R is data rate, V_{af} is voice activity factor, and E_b/N_0 is SNR (signal-to-noise-ratio).

IV. SIMULATION RESULTS

To estimate the capacity, the simulation was done in the following steps [9,10]: 1) generation of transmitted signal, 2) generation of random scatterers around the transmitter, 3) beamforming (calibration), 4) addition of channel response and noise, 5) RAKE demodulation, and 6) computation of SINR and outage probability.

For simulation examples, vehicle speed = 12km/h, BPSK modulation for data and chip sequences in the reverse link, carrier frequency $f_c = 1.8GHz$, Doppler frequency $f_d = f_c \cdot (v/c) = 20Hz$, Gold sequence, data rate = 38.4 kbps, chip rate $R_c = 1/T_c = 3.84Mcps$, the number of multipath = 2, exponential MIP, and the forgetting factor of RLS algorithm = 0.95 were assumed. The RLS algorithm makes the adaptive array to form a main beam and sidelobes in the direction of the desired multipath signal while forming nulls in the direction of the interference automatically without the knowledge of the direction of the desired signal and the interference. In a single sector of a cell, the users are uniformly distributed. The uniform linear array (ULA) of omnidirectional sensors with half wavelength antenna spacing is considered.

In Fig. 2, relative power of desired signal and interference is compared. It is shown that the desired signal is relatively larger than the interference power due to array gain of the adaptive antenna array. The interference rejection capability of the adaptive antenna array is provided from this array gain. The desired user is located at the center (0 degree) of a 120 degree sector, and the six interfering users are located within the angle spacing of 20 degrees. By the array gain, the interference rejection capability can be offered at every 20 degree spacing.

In Fig. 3, the capacity vs. fading index is shown for a single antenna and the 8 array elements. It is shown that the capacity can be increased about twice by employing the adaptive antenna array.

In. Fig. 4, the capacity vs. fading index is compared for the single carrier and multicarrier DS/CDMA system with the bandwidth fixed. It is shown that the multicarrier system achieves higher capacity than the single carrier system due to it inherent benefits such as immunity to the multipath fading.

It can be noted that the capacity does not increase gradually as the number of subcarriers increases. In general, the sensitivity due to frequency offset increases in a fading mobile channel as the number of subcarriers increases. Therefore, it is not expected that the larger number of subcarriers can achieve the better performance in every case because the user's mobility may cause the severe Doppler shift and carrier phase noise. Thus, it is not easy to find the optimum number of subcarriers theoretically because the capacity is affected too many factors.

And, the multicarrier DS/CDMA system has many benefits over the single-carrier DS/CDMA system at the cost of some implementation problems. By employing adaptive antenna array, the BER and outage performances can be greatly improved, thus the overall system capacity is expected to increase significantly compared to the case without adaptive antenna array. The conventional single carrier DS/CDMA system, in general, has the following problems: 1) since the capacity of a DS/CDMA system is limited by the MAI, the performance degrades rapidly as the number of active users increases, 2) in order to exploit the path diversity, it is necessary to apply an RAKE receiver with a sufficient number of arms, and 3) in the case of single-tone or multi-tone interference, the conventional DS/CDMA system spreads the interference signal over the whole transmission bandwidth whereas the desired signal is despread. If this interference suppression is not sufficient, some additional processing should be employed such as notch filtering. This additional operation leads to the additional receiver complexity.

However, the multicarrier DS/CDMA system typically has following advantages over the conventional DS/CDMA system: 1) the multicarrier DS/CDMA system offers more flexibility, for example, in terms of processing gain control per subcarrier or guard time control for optimization of spectral efficiency, 2) by higher-order of frequency diversity, the multicarrier DS/CDMA system achieves higher system capacity, 3) since all the processing is performed in the frequency-domain, it is easy to obtain the frequency characteristics of interference for interference suppression, 4) 'null symbol' can be used for time synchronization of each frame, 5) there is no need for equalization because all the echoes are absorbed within the guard interval, and 6) the BER performance is more gracefully degraded as the number of users increases.

V. CONCLUSIONS

The capacity of the multicarrier DS/CDMA system was estimated in a practical environment. From the simulation results, it is confirmed that the adaptive antenna array is a very effective solution to enhance the system capacity of the multicarrier DS/CDMA system. We can find applications of the results obtained in this paper to the system design for the DS/CDMA system requiring high system capacity in the future mobile communication systems.

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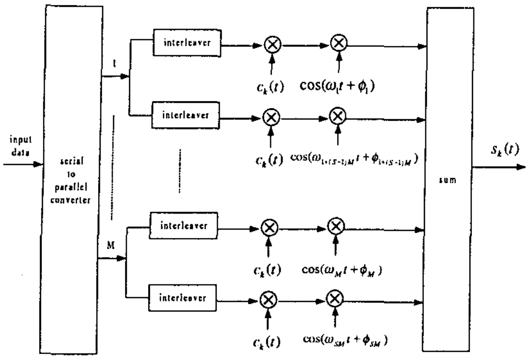
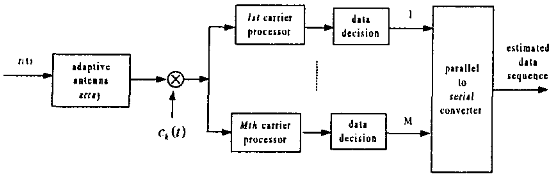
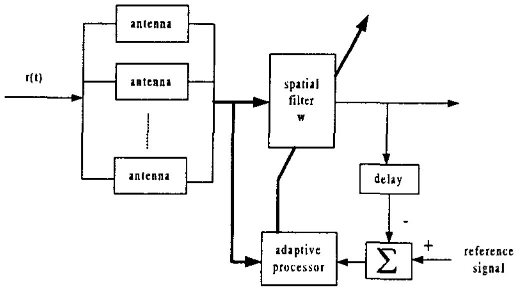


(a) Transmitter



(b) Receiver



(c) Adaptive antenna array

Fig. 1. Block diagram of multicarrier DS/CDMA system.

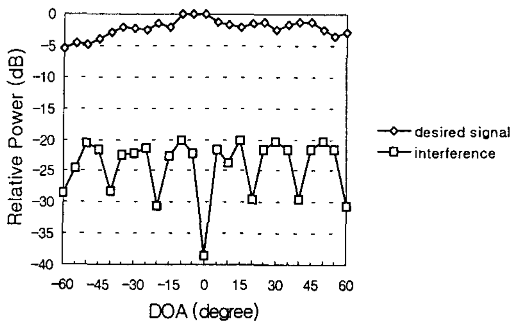


Fig. 2. Relative power of desired signal and interference.

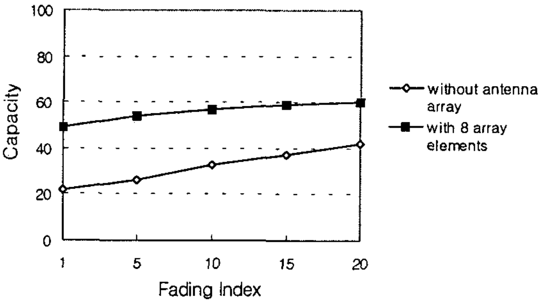


Fig. 3. Capacity vs. fading index for single antenna and 8 array elements.

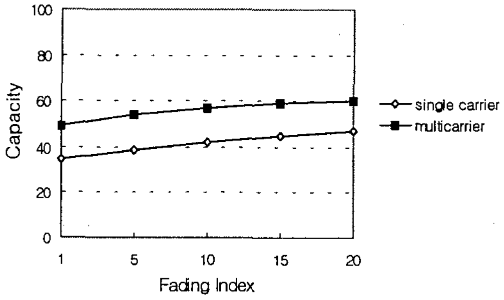


Fig. 4. Capacity vs. fading index for the single carrier and multicarrier DS/CDMA systems with the bandwidth fixed.