Performance of an Adaptive Array Cellular Base Station with a Transmision Power Control

Takeo Ohgane, Yasutaka Ogawa, and Kiyohiko Itoh
Faculty of Engineering, Hokkaido University
Kita 13 Nishi 8, Kita-ku, Sapporo 060, Japan
E-mail: ohgane@hudk.hokudai.ac.jp

I. INTRODUCTION

Most cellular systems for land mobile and/or personal communications reuse the same frequencies at several cells to increase spectral efficiency [1]. The reuse distance is determined by the extent to which cochannel interference (CCI) degrades communication quality.

Reducing cell size is a powerful way to increase spectral efficiency. However, a micro-cell is too small for land mobile communications because moving vehicles may require an excessive number of hand-overs.

An alternative proposal is to use an adaptive array at the base station antenna to avoid co-channel interference [2]-[4]. This results in reducing cluster size, and it has been reported that spectral efficiency improves 16-fold compared to a system with an omni-directional antenna [5][6].

This paper discusses performance with the transmission power control in the quasi-static Rayleigh fading channel. Computer simulation results showed the SIR performance improvement ranging from 1.5 to 4 dB. However, the improvement in the BER performance is not so remarkable, since BER is determined by SINR.

II. BASIC CONCEPT

The adaptive array consists of several antenna elements and a weight controller. Let us assume the input vector **x** and weight vector **w** in the receiver. The array output y is obtained by

$$y=\mathbf{x}^T\mathbf{w} \tag{1}$$

where ^{T} indicates the transpose. Minimizing the mean square error between the array output y and the desired signal y_{ref} provides the optimum weight $\mathbf{w}_{opt}$ as

$$\mathbf{w}_{opt}=\mathbf{R}_{xx}^{-1}\mathbf{r}_{xref} \tag{2}$$

where

$$\mathbf{R}_{xx}=E\{\mathbf{x}^*\mathbf{x}^T\} \tag{3}$$
$$\mathbf{r}_{xref}=E\{\mathbf{x}^*y_{ref}\}. \tag{4}$$

Equation (2) is called the Wiener solution [7]. Also, E{} and * indicate ensemble average operation and complex conjugate, respectively. This optimum weight provides the narrow and deep nulls in undesired signal directions for the up-link.

For the down-link, it is suggested that a replica of the receiving array pattern obtained in the up-link be applied to the transmitting pattern in the down-link [8]. This reduces unnecessary illumination by the base station. A method of synthesizing the same array pattern is achieved by using the weight vector obtained in the up-link when the transmitting frequency of the base station is equal to the receiving frequency.

Moreover, in this paper, the transmission power is controlled to maintain an adequate power. Thus, the improvement in the SIR performance is expected.

III. HEXAGONAL CELL MODEL

In this paper, we assume ordinary hexagonal cell allocation. Each cell is circular. Let us consider only the co-channel cell while assuming the following points:

1) All mobile stations are recognized as a point source from any base station.
2) Interference from outside of the neighboring cells is negligible. Then, we have 6 interference stations.
3) None of the signals are correlated.

IV. COMPUTER SIMULATION

In this simulation we deal with the time division duplexing (TDD) system. The down-link time slot is allocated after the up-link time slot. The time separation affects the Rayleigh fading correlation between up- and down-link. Adaptive antenna control is done in the up-link, and the same weight is used in the down-link. The simulation process is as follows:

A. Up-link

First we defined the objective cell (i = 0) and the six co-channel (i = 1,..., 6) cells around it. The power received at the objective base station from each mobile station was estimated with path loss, and log-normal and Rayleigh fading between them. The directivity gain of the objective base station receiver in the up-link was estimated by applying the Wiener solution (2). The directivity patterns at neighboring cells (i = 1,..., 6) were also estimated taking into account the next-neighboring cells. These patterns were used in the down-link simulation.

B. Down-link

Down- and up-link simulations were treated similarly. The same antenna array was used for transmitting. Except for its magnitude, the weight vector of the transmitter was given by that estimated in the up-link simulation; it was normalized to maintain the same SNR at the receiver. The incident power at the objective mobile station from each base station was obtained by loss term and transmitting antenna gain. The transmitting antenna pattern was formed using the same weight value given in the up-link. It provides the same pattern as one in the up-link and the automatic transmission power control, since the norm of the weight vector is in inverse proportion to the signal strength under no-AGC assumption. Here, the amplitude of the reference signal is adjusted to keep the SNR as the same as the one at the cell edge.

C. Trial repetition

The cumulative distributions of SIR were estimated by changing the location of each mobile station and their respective fading term. A mobile station location was randomly chosen within a cell area by using a uniformly distributed random number. At each location, path loss was determined directly (the propagation factor is 3.5), and log-normal fading loss was obtained from a random number (the standard deviation was 6 dB). The SIR was averaged at each position while transmitting 100 times with different Rayleigh fading. The location of the mobile station was changed 2000 times. Thus, 2000 samples of the averaged SIR, SNR, SINR were obtained on both links.

D. Approximation of BER performance

With increase of the number of interference, the sum of the interference signal behave as the Gaussian noise. In this paper, we just treated the 6 interference stations. However, as the most simple approximation, we estimated the instantaneous BER, P_e, with the instantaneous SINR, γ, as the following equation:

$$P_e = \mathrm{erfc}(\mathrm{sqrt}(\gamma/2))/2 \qquad (5)$$

where the coherent detection of QPSK signal was assumed. When the BER performance evaluation, instantaneous BER is averaged over 1000 different Rayleigh fading conditions.

E. Parameters

The number of array elements is varied from 6 to 8. The antenna elements were arranged in a circle, and the spacing between the array center and an element was 0.5 or 5.0 wavelength. The cluster size is one. The SNR at the cell edge is set to 23 dB.

V. SIMULATION RESULTS

A. CPD of SIR, SNR

Fig. 1 shows the CPD of averaged SIR and SNR for the mobile locations. The aver-

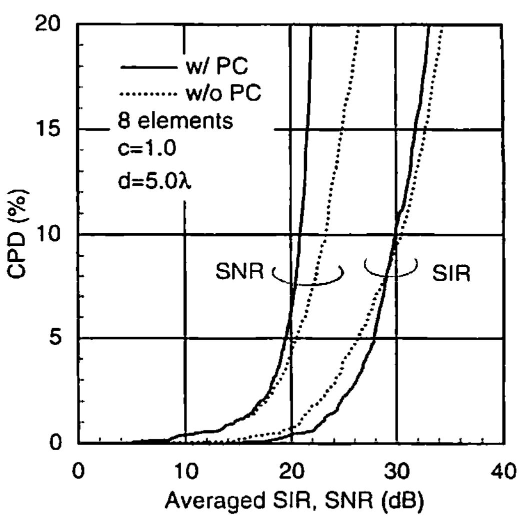

Fig.1. CPD of averaged SIR and SNR.

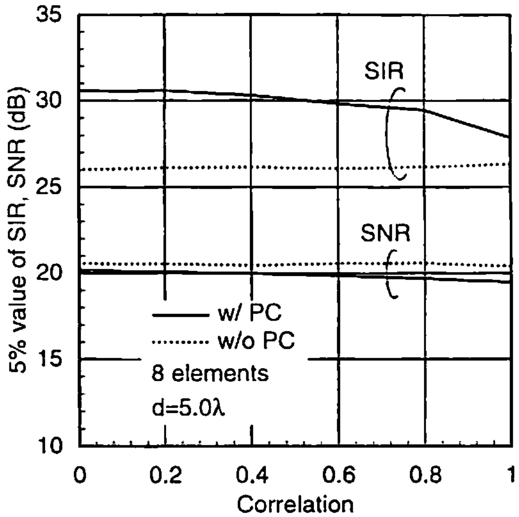

Fig. 2. 5% value of SIR and SNR vs. correlation.

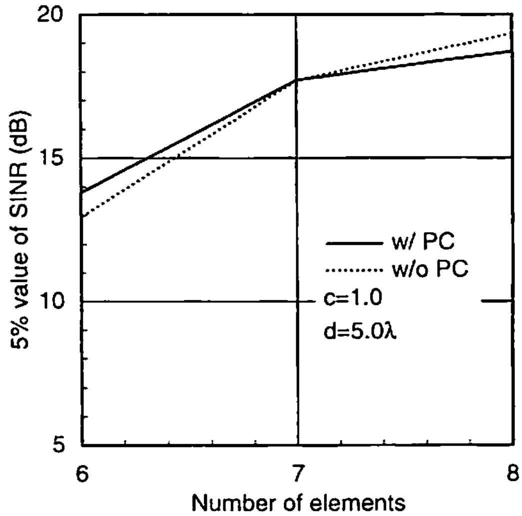

Fig. 4. 5% value of SINR vs. number of elements.

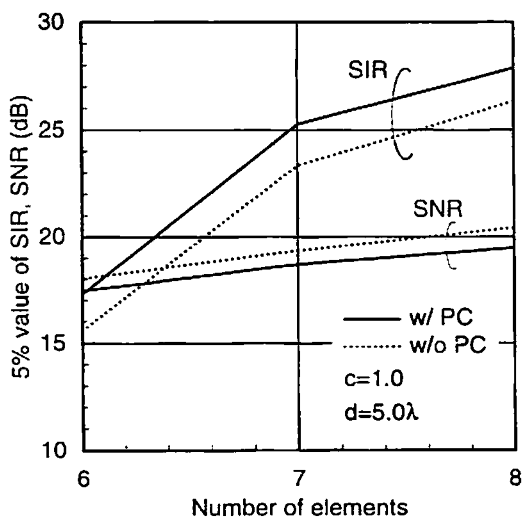

Fig. 3. 5% value of SIR and SNR vs. number of elements.

aged SNR is almost maintained to 23 dB. A few areas could not satisfy this condition, since the transmission power was limitted. However, the SIR performance is improved in comparison to one without power control.

B. Rayleigh fading correlation dependency

Fig. 2 shows the 5% value of averaged SIR and SNR for the different Rayleigh fading correlation values. The SIR performance improvement reaches about 1.5 dB in full correlation case and increases with correlation decreasing. It is a curious result, since the different fading condition should degrade the power control. This comes from the averaging. When the fading between up- and down-link is uncorrelated, the too much or too less controlled conditions occur. Thus, the averaged SIR and SNR are affected by few large values in better cases. Therefore, it should be noted that the gain increasing with lower correlation does not show the performance improvement. This is discussed later.

Fig. 3 shows the SIR and SNR performance for number of antenna elements. The SIR performance difference between from 6- and 7-elements is remarkable, since the number of degrees of freedom in the 6-element array is short to reduce all the undesired signals.

C. SINR performance

BER is defined by not only SIR but also SNR. Especially, as shown in Figs. 1 and 2, the SNR performance is worse than the SIR one. That is, the BER performance is affected by SNR mainly. Fig. 4 shows the 5% value of avaraged SINR. Here, the SINR performance with the power control is worse than one without the power control in the 8-element array case. As discussed above, the averaged SNR is maintained to a constant in the power control process. Thus, the averaged SINR seems to be worse than the case without the power control. However, with decreasing the antenna element, the SIR performance becomes comparabe to the SNR performance. Therefore, the SINR improvement by the power con-

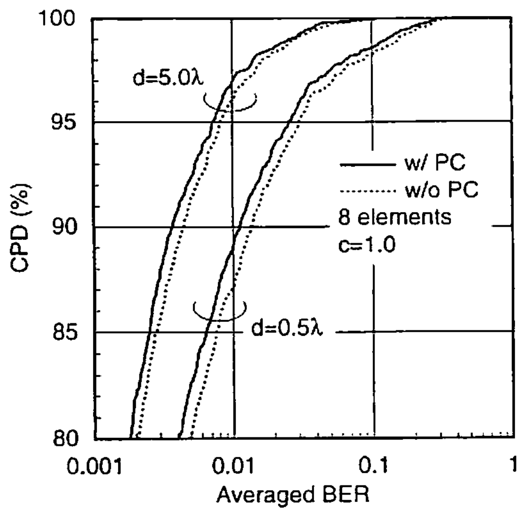

Fig. 5. CPD of averaged BER, where c=1.0.

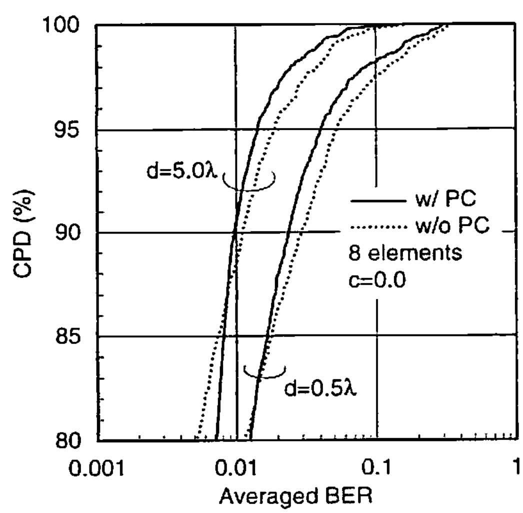

Fig. 6. CPD of averaged BER, where c=0.0.

trol can be observed.

D. BER performance

Figs. 5 and 6 show the CPD of averaged BER. In Fig. 5, the case of full correlaion, the BER performance with the power control is relatively better than one without the power control, even the averaged SINR is worse as shown in Fig. 4. The averaged BER are mainly affected a few worse cases. The power control reduces not only the high SNR condition but also the worse SIR one. Therefore, the BER performance is improved even when it is not remarkable.

Fig. 6, the uncorrelated condition case shows the degradation of BER performance. This result supports the discussion for the results in Fig. 2.

VI. CONCLUSIONS

The performance with a transmission power control in the quasi-static Rayleigh fading channel was discussed. It was shown that the power control improved averaged SIR. With full correlation between up- and down-link fading environment, the obtained gain in 5% value of averaged SIR was about 1.5 dB. However, the BER performance improvement was not so remarkable, since the BER was affected by SNR mainly. The better BER performance was obtained in the wider antenna separation and full correlation case.

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