Complexity-reduced Per-Antenna Multiple Access Interference Cancellation for DAN Using DS-CDMA

Shohei INOSHITA† Hiroyuki MIYAZAKI† and Fumiyuki ADACHI‡
Dept. of Communication Engineering, Graduate School of Engineering, Tohoku University
6-6-05 Aza-Aoba, Aramaki, Aoba-ku, Sendai, 980-8579 Japan
†{inoshita, miyazaki}@mobile.ecei.tohoku.ac.jp, ‡adachi@ecei.tohoku.ac.jp

***Abstract*—DS-CDMA allows all accessing users to share the same carrier frequency and hence, can alleviate the sophisticated channel management problem. Recently, we investigated a distributed antenna network (DAN) using direct-sequence code division multiple access (DS-CDMA) with joint antenna diversity and equalization and showed that DAN achieves higher uplink capacity than centralized antenna network (CAN). The uplink capacity is limited due to multiple access interference (MAI). In this paper, to further improve the uplink capacity, we propose a complexity-reduced per-antenna MAI cancellation before diversity combining, which is suitable for DAN using DS-CDMA. In the per-antenna MAI cancellation, first, interfering users on each antenna are sorted in descending order of the instantaneous received power. Then, a predetermined number of interfering users having the highest received powers are selected on each antenna to be cancelled in the frequency-domain before diversity combining. It is shown by computer simulation that per-antenna MAI cancellation before diversity combining achieves almost the same uplink capacity as full MAI cancellation after diversity combining.**

Keywords-DAN; DS-CDMA; Uplink capacity; CCI; TPC; MAI cancellation

I. INTRODUCTION

Transmission quality of a broadband wireless transmission is degraded due to propagation path loss, shadowing loss and frequency-selective fading [1]. In the conventional centralized antenna network (CAN) with base stations equipped with co-located antennas, the impact of the propagation path loss and the shadowing loss cannot be mitigated while the impact of frequency-selective fading can be sufficiently mitigated by using equalization and antenna diversity [2]. Therefore, a high transmit power is required for a user near the cell edge. One attractive solution to improve the transmission quality of the cell edge user is to introduce the distributed antenna network (DAN) [3-4]. In DAN, many antennas are spatially distributed in each cell. By choosing a few antennas close to a user, the problem due to propagation path loss and the shadowing loss can be mitigated. Thus, a good transmission performance can be achieved over an entire service area.

Which multi-access technique should be used for DAN is an important issue. In general, there are three multi-access techniques: time division multi-access (TDMA), frequency division multi-access (FDMA), and direct spread code division multi-access (DS-CDMA) [5]. In TDMA and FDMA, orthogonal channels are used and a sophisticated channel management is necessary to adapt to the changing channel state information (CSI). On the other hand, DS-CDMA allows all accessing users to reuse the same carrier frequency and hence, can alleviate the sophisticated channel management problem. The use of the minimum mean square error (MMSE) based frequency-domain equalization (FDE) achieves a good transmission performance [6-9]. In this paper, we consider DS-CDMA in DAN. Distributed antenna diversity combined with FDE (similar to site diversity in CAN) can be used [10]. However, the multiple access interference (MAI) limits the uplink capacity.

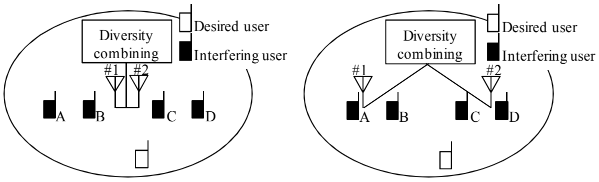
The use of MAI cancellation improves the bit error rate (BER) performance [11-13]. In CAN, however, the MAI cancellation requires CSIs associated with all users, resulting in high computational complexity. On the other hand, in DAN, since the number of simultaneously accessing users per antenna is a few, the complexity problem is alleviated.

In conventional MAI cancellation, interfering users are ranked in descending order of the instantaneous received interference power after diversity combining and a predetermined number of interfering users are cancelled from the diversity-combined signal. As an example, let's consider a case of single desired user and four strong interfering users (users A, B, C, and D) in Fig. 1. In the case of CAN, we need to cancel all four strong interfering users if we want to improve transmission performance. However, in the case of DAN, antennas are spatially distributed and therefore, only a few strong interfering users may exist on each distributed antenna and furthermore they may be different from antenna to antenna (i.e., A and B are strong interfering users on antenna #1 while C and D on antenna #2). This fact is exploited in this paper and we propose a complexity-reduced per-antenna MAI cancellation before diversity combining for DAN using DS-CDMA.

In the per-antenna MAI cancellation, first, interfering users on each antenna are sorted in descending order of the instantaneous received power. Then, a predetermined number of interfering users having the highest received powers are selected on each antenna to be cancelled in the frequency-domain before diversity combining. The number of interfering users to be cancelled per antenna is much smaller than the full MAI cancellation after diversity combining, thereby leading to a reduced-complexity MAI cancellation.

We investigate, by computer simulation, the DS-CDMA uplink capacity of DAN with per-antenna MAI cancellation and show that the per-antenna MAI cancellation before diversity combining achieves almost the same uplink capacity as the full MAI cancellation after diversity combining.

The reminder of this paper is organized as follows. The DS-CDMA uplink model is described in Sect. II. Section III describes the proposed per-antenna MAI cancellation. The computer simulation results on the BER performance are presented in Sect. IV. Section V offers some conclusions.



(a)CAN (b)DAN

Figure 1. An example of interference environment.

II. UPLINK MODEL

A. Network Model

In this paper, multi-user and multi-cell environment is considered. Fig. 2 illustrates the models of DAN and CAN with N_{total}=7 antennas in a multi-cell environment. The center cell (c=0) is assumed to be the cell of interest. Assuming the cluster size 1, there are 6 CCI cells (c=1~6) for the cell of interest (c=0). In our DAN model, it is assumed that each distributed antenna covers the hexagonal area with a radius of $R' = R/\sqrt{7}$, where R represents the cell radius of the CAN. All distributed antennas are connected to the signal processing center (SPC) by optical links (ideal signal transmission between each distributed antenna and the SPC is assumed). In CAN, all antennas are co-located at the center of the cell.

We assume that U active users are randomly located in each cell and user terminal equips with single antenna (i.e. N_t=1). Each user selects N_r antennas in order of decreasing the instantaneous received power from N_{total} antennas.

B. Channel Model

The broadband propagation channel is characterized by the propagation path loss, the log-normally distributed shadowing loss, and the frequency-selective fading. Assuming a frequency-selective channel composed of L distinct paths, the channel impulse response, $\tilde{h}^{(c,u \to c',n_r)}(t)$, of the link between the u-th user in the c-th cell and the n_r-th received antenna in the c'-th cell is expressed as

$$\tilde{h}^{(c,u \to c',n_r)}(t) = \sum_{l=0}^{L-1} \tilde{h}_l^{(c,u \to c',n_r)} \cdot \delta\left(t - \tau_l^{(c,u \to c',n_r)}\right), \qquad (1)$$

where $\tilde{h}_l^{(c,u \to c',n_r)}$ is the l-th complex valued path gain, including the impacts of the propagation path loss and the shadowing loss, of the link between the u-th user in the c-th cell and the n_r-th received antenna in the c'-th cell. It is expressed as

$$\tilde{h}_l^{(c,u \to c',n_r)} = \sqrt{D^{(c,u \to c',n_r)^{-\alpha}} \cdot 10^{-\frac{\eta^{(c,u \to c',n_r)}}{10}}} \cdot g_l^{(c,u \to c',n_r)}, \qquad (2)$$

where $D^{(c,u \to c',n_r)}$ is the distance between the u-th user in the c-th cell and the n_r-th received antenna in the c'-th cell. α denotes the path loss exponent and $\eta^{(c,u \to c',n_r)}$ is the shadowing loss in dB between the u-th user in the c-th cell and the n_r-th received antenna in the c'-th cell. $g_l^{(c,u \to c',n_r)}$ and $\tau_l^{(c,u \to c',n_r)}$ are the l-th complex valued path gain with $E[\sum_{l=0}^{L-1} |g_l^{(c,u \to c',n_r)}|^2] = 1$ and the time delay of the l-th path, respectively.

The instantaneous received signal power at the n_r-th received antenna in the c'-th cell from the u-th user in the c-th cell, $P_r^{(c,u \to c',n_r)}$, is expressed as

$$\begin{aligned} P_r^{(c,u \to c',n_r)} &= p_t^{(c,u)} \cdot \sum_{l=0}^{L-1} \left| \tilde{h}_l^{(c,u \to c',n_r)} \right|^2 \\ &= p_t^{(c,u)} \cdot D^{(c,u \to c',n_r)^{-\alpha}} \cdot 10^{-\frac{\eta^{(c,u \to c',n_r)}}{10}} \cdot \sum_{l=0}^{L-1} \left| g_l^{(c,u \to c',n_r)} \right|^2 \end{aligned}, \qquad (3)$$

where $p_t^{(c,u)}$ represents the actual transmit power of the u-th user in the c-th cell, and (3) can be rewritten as

$$\begin{aligned} P_r^{(c,u \to c',n_r)} &= P_t^{(c,u)} \cdot d^{(c,u \to c',n_r)^{-\alpha}} \cdot 10^{-\frac{\eta^{(c,u \to c',n_r)}}{10}} \cdot \sum_{l=0}^{L-1} \left| g_l^{(c,u \to c',n_r)} \right|^2 \\ &= P_t^{(c,u)} \cdot \sum_{l=0}^{L-1} \left| \hat{h}_l^{(c,u \to c',n_r)} \right|^2 \end{aligned}, \qquad (4)$$

where $P_t^{(c,u)} = p_t^{(c,u)} \cdot R^{-\alpha}$ and $d^{(c,u \to c',n_r)} = D^{(c,u \to c',n_r)} / R$, denote the normalized transmit power and the normalized distance, respectively. $\hat{h}_l^{(c,u \to c',n_r)}$ is the normalized l-th complex valued path gain and expressed as

$$\hat{h}_l^{(c,u \to c',n_r)} = \sqrt{\left(D^{(c,u \to c',n_r)} / R\right)^{-\alpha} \cdot 10^{-\frac{\eta^{(c,u \to c',n_r)}}{10}}} \cdot g_l^{(c,u \to c',n_r)}. \qquad (5)$$

III. DS-CDMA WITH MAI CANCELLATION

A. Transmit/Receive Signal Representation

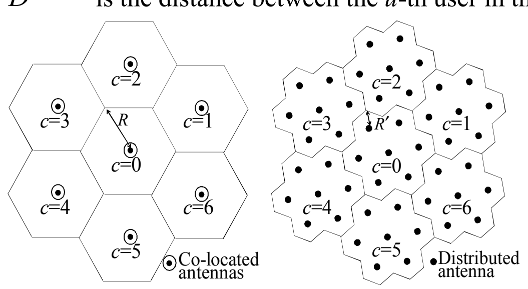
The DS-CDMA uplink transmitter/receiver structure is illustrated in Fig. 3. In this paper, the chip-spaced discrete-time signal representation is used.

All of the users in each cell are transmitting their signals. We consider the transmission of one block of N_c chips, where N_c denotes the block length for fast Fourier transform (FFT). At the transmitter of the u-th user (u=0~(U–1)) in the c-th cell (c=0~6), binary data sequence is transformed into data-modulated symbol sequence $\{d^{(c,u)}(n);\ n=0\sim(N_c/SF-1)\}$, and then spread by multiplying it with a user-specific long pseudo noise (PN) sequence $c^{(c,u)}(t)$. The resultant DS-CDMA signal, $\{\tilde{s}^{(c,u)}(t);\ t=0\sim(N_c-1)\}$, can be expressed using the equivalent baseband representation as

$$\tilde{s}^{(c,u)}(t) = \sqrt{2P_t^{(c,u)}}\, s^{(c,u)}(t), \qquad (6)$$

where

$$s^{(c,u)}(t) = d^{(c,u)}(\lfloor t/SF \rfloor) c^{(c,u)}(t), \qquad (7)$$



(a)CAN (b)DAN

Figure 2. Network models.

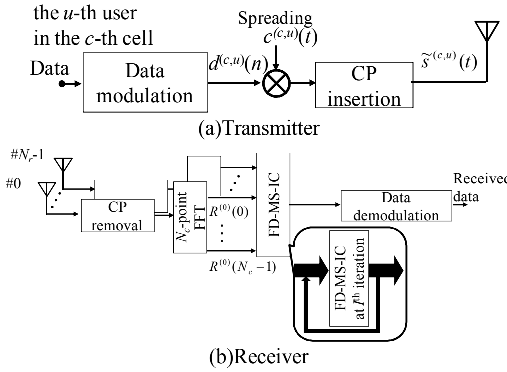


Figure 3. Transmitter/receiver structure.

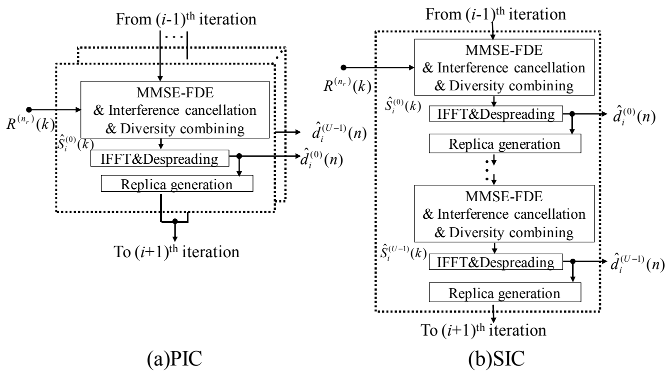


Figure 4. FD-MS-IC structure.

and $\lfloor x \rfloor$ represents the largest integer smaller than or equal to x. The last N_g chips of each block are copied as a cyclic prefix (CP) and inserted into the guard interval at the beginning of each block.

In the following, without loss of generality, we assume that the u-th user in the c-th cell is the desired user 0. The n_r-th antenna which is selected by the desired user receives the signal from the desired user 0 and $u'(n_r)$ interfering user ($u'(n_r)$=1~U–1 are MAI users, $u'(n_r)$=U~7U–1 are CCI users) in the 7 surrounding cells where the n_r-th antenna exists.

At the receiver, after CP removal, the received signal is transformed into the frequency-domain signal by N_c-point FFT. The frequency-domain received signal at the n_r-th received antenna $\{R^{(n_r)}(k)$; k=0~(N_c–1)} can be expressed as

$$\begin{aligned}R^{(n_r)}(k) &= \sqrt{2P_t^{(0)}}H^{(u,0\to n_r)}(k)S^{(0)}(k)\\ &+ \sum_{u'(n_r)=1}^{U-1}\sqrt{2P_t^{(u'(n_r))}}H^{(u'(n_r),0\to n_r)}(k)S^{(u'(n_r))}(k)\\ &+ \sum_{u'(n_r)=U}^{7U-1}\sqrt{2P_t^{(u'(n_r))}}H^{(u'(n_r),0\to n_r)}(k)S^{(u'(n_r))}(k)\\ &+\Pi^{(n_r)}(k)\end{aligned}, \quad (8)$$

where $S^{(v)}(k)$ is the k-th frequency component of $s^{(v)}(t)$. $P_t^{(v)}$ is the normalized transmit power of user v (v=0~(7U–1)). $H^{(v',v\to n_r)}(k)$ denotes the k-th frequency channel transfer function between the v'-th user and the n_r-th antenna selected by the v-th user. $\Pi^{(n_r)}(k)$ is the zero-mean complex valued additive white Gaussian noise (AWGN) having variance $2N_0/T_c$ with N_0 and T_c representing the single-sided power spectrum density of the AWGN and chip duration, respectively. The first term represents the desired signal component, the second the MAI component, the third the CCI component and the fourth the noise component in (8). Then, frequency-domain multi-stage interference cancellation (FD-MS-IC) is performed to obtain a sequence of decision variables for data demodulation. After FD-MS-IC, the time-domain signal is demodulated.

In this paper, we consider fast transmit power control (TPC) [2, 10] so that the instantaneous SNR after despreading is kept at the target SNR. The normalized transmit power $P_t^{(v)}$ of the v-th user is given by

$$P_t^{(v)} = \frac{N_0}{2T_c}\frac{SNR_{\text{target}}}{\sum_{n_r=0}^{N_r-1}\sum_{l=0}^{L-1}\left|h_l^{(v,v\to n_r)}\right|^2}\frac{1}{SF}, \quad (9)$$

where $h_l^{(v,v\to n_r)}$ represents the normalized l-th complex valued path gain between the v-th user and the n_r-th antenna selected by the v-th user. SNR_{target} is the target SNR.

B. FD-MS-IC

In this paper, we assume two types of MAI cancellation; parallel interference cancellation (PIC) and successive interference cancellation (SIC) [11]. The structure of the i-th cancellation stage is illustrated in Fig. 4. Each stage consists of MMSE-FDE, interference cancellation, diversity combining, inverse FFT (IFFT), despreading, and replica generation.

In PIC, at i=1st stage, data of each user is detected thought MMSE-FDE, diversity combining, IFFT, and despreading. From i=2nd stage onwards, the ICI replica and MAI replica generated based on the log-likelihood ratio (LLR) given by soft decision variable at i–1-th stage are subtracted from the received signal after MMSE-FDE for each desired user.

On the other hand, in SIC, at first, the data of the user who has the highest received signal-to-interference plus noise power ratio (SINR) is detected though MMSE-FDE, diversity combining, IFFT, and despreading. Then, the ICI replica and MAI replica at i-th or i–1-th satage are subtracted from the received signal after MMSE-FDE for all users, according to the instantaneous received SINR.

In both of PIC and SIC, the performance becomes better by repeated this procedure a sufficient number of times. Furthermore, in this paper, we propose a per-antenna MAI cancellation for the DS-CDMA uplink. In the per-antenna MAI cancellation, first, all users in the cell are sorted per antenna in descending order of the instantaneous received power. Then, some users with the highest received powers at the received antenna are selected and cancelled on each distributed antenna. On the other hand, in conventional MAI cancellation, a predetermined number of interfering users having the highest received powers after antenna diversity combining are selected and cancelled from the diversity-combined signal. We assume that U_c (U_c<U–1) users per antenna are selected and cancelled.

1) PIC

First, at the i=1st stage, MMSE-FDE and diversity combining are carried out. The received signal after diversity combing is given as

$$\hat{R}(k) = \sum_{n_r=0}^{N_r-1}W_1^{(n_r)}(k)R^{(n_r)}(k), \quad (10)$$

where $W_1^{(n_r)}(k)$ is MMSE-FDE weight. This MMSE-FDE weight is determined so as to minimize the mean square error between the desired transmit signal and the received signal after equalization and diversity combining under the assumption that the spatial correlation of channels is sufficiently low. The MMSE-FDE weight is given as

$$W_1^{(n_r)}(k)=\frac{\Gamma^{(0)}H^{(0,0\to n_r)^*}(k)}{\left[\begin{array}{l}\Gamma^{(0)}\left|H^{(0,0\to n_r)}(k)\right|^2\\ +\sum_{u'(n_r)=1}^{U-1}\Gamma^{(u'(n_r))}\left|H^{(u'(n_r),0\to n_r)}(k)\right|^2\\ +\sum_{u'(n_r)=U}^{7U-1}\Gamma^{(u'(n_r))}\left|H^{(u'(n_r),0\to n_r)}(k)\right|^2+1\end{array}\right]}, \quad (11)$$

where

$$\Gamma^{(v)}=\frac{P_t^{(v)}T_c}{N_0}. \quad (12)$$

After diversity combining, the frequency-domain received signal is transformed by N_c-point IFFT into the time-domain signal. Then, despreading and demodulation are carried out.

From i=2nd stage onwards, after MMSE-FDE and diversity combining, the residual ICI replica and MAI replica generated based on LLR given by soft decision variable at $i-1$-th stage are subtracted from the received signal. The received signal after interference cancellation is given as

$$\hat{S}_i^{(0)}(k)=\sum_{n_r=0}^{N_r-1}\left[\begin{array}{l}W_i^{(n_r)}(k)R^{(n_r)}(k)\\ -M_i^{(n_r,0)}(k)\bar{S}_{i-1}^{(0)}(k)\\ -\sum_{u_c=0}^{U_c-1}M_i^{(n_r,f(n_r,u_c))}(k)\bar{S}_{i-1}^{(f(n_r,u_c))}(k)\end{array}\right], \quad (13)$$

where $\bar{S}_{i-1}^{(u)}(k)$ is the frequency-domain transmit signal replica of the u-th user. This replica is given as

$$\bar{S}_{i-1}^{(u)}(k)=\sum_{t=0}^{N_c-1}\left\{\sqrt{\frac{2P_t^{(u)}}{T_c}}\bar{d}_{i-1}^{(u)}(\lfloor t/SF\rfloor)c^{(u)}(t)\right\}\exp\left(-j2\pi k\frac{t}{N_c}\right), \quad (14)$$

where $\{\bar{d}_{i-1}^{(u)}(n)$; n=0~$(N_c/SF-1)\}$ denotes the soft decision replica at the $i-1$-th stage. $W_i^{(n_r)}(k)$ and $M_i^{(n_r,f(n_r,u_c))}$ are MMSE-FDE weight and cancellation weight at the i-th stage, respectively. They are given as

$$W_i^{(n_r)}(k)=\frac{\Gamma^{(0)}H^{(0,0\to n_r)^*}(k)}{\left[\begin{array}{l}\Gamma^{(0)}\rho_{i-1}^{(0)}\,|H^{(0,0\to n_r)}|^2\\ +\sum_{u_c=0}^{U_c-1}\Gamma^{(f(n_r,u_c))}\rho_{i-1}^{(f(n_r,u_c))}\,|H^{(f(n_r,u_c),0\to n_r)}(k)|^2\\ +\sum_{u_c=U_c}^{U-1}\Gamma^{(f(n_r,u_c))}\,|H^{(f(n_r,u_c),0\to n_r)}(k)|^2\\ +\sum_{u'(n_r)=U}^{7U-1}\Gamma^{(u'(n_r))}\left|H^{(u'(n_r),0\to n_r)}(k)\right|^2+1\end{array}\right]}, \quad (15)$$

$$M_i^{(n_r,u_c)}(k)=\begin{cases}W_i^{(n_r)}(k)H^{(0,0\to n_r)}(k)\\ -\frac{1}{N_c}\sum_{k=0}^{N_c-1}W_{i-1}^{(n_r)}(k)H^{(0,0\to n_r)}(k) & \text{if } u_c=0\\ W_i^{(n_r)}(k)H^{(u_c,0\to n_r)}(k) & \text{otherwise}\end{cases}, \quad (16)$$

where $\rho_{i-1}^{(f(n_r,u_c))}$ denotes the accuracy of chip replica which is given as

$$\rho_{i-1}^{(f(n_r,u_c))}=\frac{1}{N_c}\sum_{t=0}^{N_c-1}\left[1-\left(2P_t^{(f(n_r,u_c))}\right)^{-1}\left|\bar{s}_{i-1}^{f(n_r,u_c)}(t)\right|^2\right]. \quad (17)$$

The function $f(n_r,u_c)$ ($f(n_r,u_c)$=1~$U-1$) denotes the user who has the u_c-th highest received power at the n_r-th antenna selected by the desired user 0 excluding user 0.

These operations are repeated I times, the frequency-domain received signal after interference cancellation transformed into the time-domain signal by IFFT. Finally, despreading and demodulation are carried out.

2) SIC

First, the desired users are sorted in order of decreasing the instantaneous received SINR. In this paper, without loss of generality, we assume as .

$$\gamma^{(0)}\geq\gamma^{(1)}\geq\cdots\geq\gamma^{(U-1)}, \quad (18)$$

where $\gamma^{(u)}$ represents the received SINR of the v-th user expressed as

$$\gamma^{(u)}=\frac{\sum_{n_r=0}^{N_r-1}\Gamma^{(u)}\left|H^{(u,u\to n_r)}\right|^2}{\sum_{n_r=0}^{N_r-1}\sum_{\substack{u'(n_r)=0\\ u'(n_r)\neq u}}^{7U-1}\Gamma^{(u'(n_r))}\left|H^{(u'(n_r),u\to n_r)}\right|^2+1}. \quad (19)$$

Then, MMSE-FDE and interference cancellation are carried. We explain about the data detection of the user who has the u-th highest SINR. In SIC, the soft decision replicas are generated by the soft decision variable of the 0th user to $u-1$-th user at the $i-1$ stage and the $u+1$-th user to the $U-1$-th user at the i stage. This soft decision replicas are re-spreading and are transformed into frequency-domain signal by FFT. Then, ICI replica and MAI replica which are given by the soft decision replicas and channel transfer functions are subtracted from received signal to obtain the received signal reduced ICI and MAI.

MMSE-FDE weight and cancellation weigh are given in the same way as PIC. However, we omit it for want of space.

IV. COMPUTER SIMULATION

QPSK data modulation is considered. Long PN sequence is used as the spreading code and spreading factor SF is set to SF=16. FFT block size N_c and CP length N_g are respectively set to N_c=256 and N_g=32. The channel is assumed to be a frequency-selective block Rayleigh fading having chip spaced L=16 path uniform power delay profile. The path loss exponent α and the shadowing loss standard deviation σ are assumed to be α=3.5 and σ=7.0dB, respectively. We assume the interference-limited channel (SNR_{target}>>1) and ideal TPC. Perfect channel estimation is also assumed. The number of received antennas is assumed N_r=3. The number of stage iterations I is set to I=6.

In this paper, we define the uplink capacity as follows. At first, the outage probability is defined as the probability that the local average BER exceeds the required BER. The uplink capacity is defined as the maximum number $U_{\max}$ of supportable users normalized by the spreading factor *SF*. In this paper, the required BER and the allowable outage probability are set as BER=10^{-2} and Q=0.1, respectively.

Fig. 5 shows the outage probability as a function of the normalized number of users *U*/*SF* in DS-CDMA with PIC and SIC. For comparison, no interference cancellation case is also plotted. It is shown in Fig. 5 that applying MAI cancellation can achieve lower outage probability due to mitigating the impact of MAI. Furthermore, the improvement effect of DAN is larger than that of CAN. The reason for this is given below. In uplink DS-CDMA, MAI and CCI, that are intra-cell interference and inter-cell interference, limit the performance. Therefore, when the impact of CCI is much larger, the improvement effect of MAI cancellation is little because MAI cancellation can't operate normally. In CAN, the impact of CCI is large because antennas are co-located and hence, the improvement effect of MAI cancellation is little due to low accuracy of chip replica. On the other hand, in DAN, the impact of both of MAI and CCI can be mitigated because distributed antennas are geographically separated. Therefore, the improvement effect of MAI cancellation is large. It is seen from Fig.5 that the DS-CDMA uplink capacity of DAN with PIC (SIC) is 1.1 (1.0) which is 17 (16) times higher than that of CAN with PIC (SIC) when U_c=U−1 (all of the users in the cell are cancelled).

It is also shown from Fig.5 that the improvement effect of MAI cancellation is large even if the number of cancelling users per antenna is a few. When N_{total}=7, N_r=3, the uplink capacity of DS-CDMA DAN using per-antenna PIC (SIC) with U_c=5 is 1.0 (0.94) and it is almost the same as that of DS-CDMA DAN with full PIC (SIC) . This is because that in DAN, the number of simultaneously accessing users per antenna is a few and the impact of MAI produced by the user who located far from distributed antenna is little. As a consequence, the improvement effect of MAI cancellation is large only to cancel the a few users who produce large interference in each distributed antenna.

V. CONCLUSION

In this paper, we propose a complexity-reduced per-antenna MAI cancellation before diversity combining, which is suitable for DAN using DS-CDMA. Since the number of simultaneously accessing users per antenna is a few in DAN, a few users are only cancelled in the per-antenna MAI cancellation. In the per-antenna MAI cancellation, first, interfering users on each antenna are sorted in descending order of the instantaneous received power. Then, a predetermined number of interfering users having the highest received powers are selected on each antenna to be cancelled in the frequency-domain before diversity combining. It was shown by computer simulation that per antenna MAI cancellation achieves almost the same uplink capacity as full MAI cancellation.

Evaluation of computational complexity including channel estimation is left as our future study.

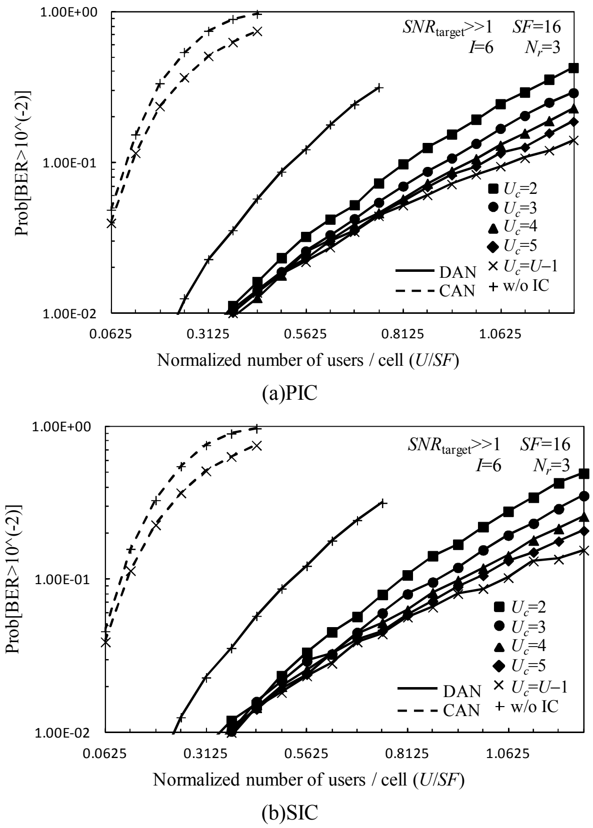


Figure 5. BER outage probability.

REFERENCES

[1] A. Goldsmith, Wireless Communication, Cambridge University Press, 2005.

[2] F. Adachi, M. Sawahashi, and H. Suda, "Wideband DS-CDMA for next-generation mobile communications systems," IEEE Commun. Mag., Vol. 36, pp. 56-69, Sep. 1998.

[3] F. Adachi and K. Takeda, T. Yamamoto, R. Matsukawa, and S. Kumagai, "Recent advances in single-carrier distributed antenna network," Wireless Communications and Mobile Computing, Vol. 11, No. 12, pp. 1551-1563, Dec. 2011.

[4] T. Yamamoto and F. Adachi, "Uplink throughput performance of single-carrier MIMO spatial multiplexing in distributed antenna network," Proc. The 9th IEEE Asia Pacific Wireless Communication Symposium (APWCS 2012), Kyoto, Japan, Aug. 2012.

[5] F. Adachi, "Wireless past and future - evolving mobile communications systems," IEICE Trans. Fundamentals, Vol. E84-A, pp. 55-60, Jan. 2001.

[6] F. Adachi and K. Takeda, "Bit error rate analysis of DS-CDMA with joint frequency-domain equalization and antenna diversity combining," IEICE Trans. Commun., Vol. E87-B, No. 10, pp. 2991-3002, Oct. 2004.

[7] F. Adachi, T. Sao, and T. Itagaki, "Performance of multicode DS-CDMA using frequency domain equalization in a frequency selective fading channel," IEE Electronics Letters, vol. 39, No.2, pp. 239-241, Jan. 2003.

[8] F. Adachi, D. Garg, S. Takaoka, and K. Takeda, " Broadband CDMA techniques," (invited) IEEE Wireless Commun. Mag., Vol. 12, No. 2, pp. 8-18, Apr. 2005.

[9] D. Falconer, S. L. Ariyavistakul, A. BenyaminSeeyar, and B. Edison, "Frequency domain equalization for single-carrier broadband wireless systems," IEEE Commun. Mag., Vol. 40, No. 4, pp. 58-66, Apr. 2002.

[10] S. Inoshita, H. Miyazaki, and F. Adachi, "Uplink capacity and required transmit power of DS-CDMA DAN," 2013 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS), Okinawa, Japan, Nov. 2013.

[11] K. Ishihara, K. Takeda, and F. Adachi, "Frequency-domain multi-stage soft interference cancellation for DS-CDMA uplink signal transmission," IEICE Trans. Commun., Vol. E90-B, No. 5, pp. 1152-1161, May 2007.

[12] S. Tomasin and N. Benvenuto, "Equalization and multiuser interference cancellation in CDMA systems," Proc. 6th International Symposium on WPMC, Vol. 1, pp. 10-14, Yokosuka, Japan, Oct. 2003.

[13] K. Jamal and E. Dahlman, "Multi-stage serial interference cancellation for DS-CDMA," Proc. IEEE 46th Vehicular Technology Conf., pp. 671-675, Apr. 1996.