

[ポスター講演] 不均一ユーザ分布環境における DS-CDMA DAN のための適応アンテナ毎干渉キャンセラ

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あらまし 複数アンテナをセル内に分散配置する分散アンテナネットワーク(DAN)ではフェージングばかりではなく、シャドウイング損失および伝搬損失の影響を同時に低減でき、セル全域にわたって優れた伝送品質を達成できる。また擬似直交拡散符号を用いる直接拡散符号分割マルチアクセス(DS-CDMA)と干渉キャンセラを組み合わせることで、複雑なチャネル割り当て問題を回避しつつ、多数のユーザを同時に収容することが出来る。以前筆者らは、演算量を削減しつつ優れた上りリンク容量を達成するために、分散アンテナ毎にキャンセル対象ユーザを選択するアンテナ毎干渉キャンセラ(PAIC)を提案した。この PAIC ではキャンセルユーザ数を全ての分散アンテナで同じとしていたため、周辺に多数のユーザが存在するアンテナではキャンセルユーザ数が不足すること、周辺のユーザが少ないアンテナではキャンセルユーザ数が過剰であるという問題があった。そこで本稿ではユーザ分布の偏りの変化に対応してアンテナ毎のキャンセルユーザ数を適応的に変化させる適応アンテナ毎干渉キャンセラ(APAIC)を提案する。分散アンテナはそれぞれ固有のパイロット信号を送信する。各ユーザはパイロットの瞬時受信電力を測定し、レベルの大きい順にあらかじめ決められた本数分だけアンテナを選択し、選択したアンテナ全てにユーザ番号と選択順位を通知する。APAIC では、分散アンテナごとにそれを受信アンテナとして選択しているユーザおよびそのアンテナの選択順位を示すテーブルを作成する。各分散アンテナではそのテーブルを参照し、その中から受信アンテナとしての選択順位がしきい値以上のユーザをキャンセルする。計算機シミュレーションから、APAIC はユーザ分布に偏りがある環境下で、高い上りリンク容量を達成できることを明らかにしている。

キーワード DAN, DS-CDMA, 上りリンク容量, 干渉キャンセラ

[Poster Presentation] Adaptive Per-antenna Interference Cancellation for DS-CDMA DAN in A Non-uniform User-distribution

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Abstract Distributed antenna network (DAN), in which many antennas are spatially distributed, can mitigate the negative impact of not only the fading but also propagation path loss and shadowing loss, and accordingly, achieves a good transmission performance in entire the service area. Beside, the combination of direct-sequence code division multiple access (DS-CDMA) using quasi-orthogonal code and interference cancellation can accommodate many users in a cell while alleviating complex channel allocation problem. Recently, we proposed the per-antenna interference cancellation (PAIC) for DS-CDMA DAN in order to achieve a good uplink capacity while reducing computational complexity. In the conventional PAIC, the numbers of users to be cancelled in antenna whose coverage area has many and few users are insufficient and excessive respectively, because the number of users to be cancelled is the same among all distributed antennas. In this paper, we propose the adaptive per-antenna interference cancellation (APAIC) to change the number of users to be cancelled according to the user distribution. Distributed antennas transmit their own pilot signals. Each user selects the received antennas in the descending order of the instantaneous received pilot signal power and reports the user index and the rank of selected antenna to each of selected antennas. In APAIC, each antenna has a user table containing the indices of users who have selected that antenna and the ranks of that antenna. Each antenna looks up the user table and cancels the users who are selecting it higher than the prescribed ranking threshold. We show by computer simulation that our proposed APAIC achieves a higher uplink capacity than the

conventional PAIC in an environment of non-uniform user distribution.

Keyword DAN, DS-CDMA, uplink capacity, interference cancellation

1. Introduction

Transmission quality of a broadband wireless is degraded due to propagation path loss, shadowing loss and frequency-selective fading [1]. The antenna diversity reception is a well-known technique to improve the transmission performance [2]. However, if diversity antennas are co-located at the same base station (this is called the centralized antenna network (CAN)), propagation path loss and shadowing loss remain intact while the performance degradation due to frequency-selective fading can be sufficiently mitigated. On the other hand, if diversity antennas are spatially distributed (this is called the distributed antenna network (DAN)) [3-5], the transmission performance degradation due to propagation path loss and shadowing loss can be mitigated.

Multi-access technique suitable for DAN is an interesting issue. There are three multi-access techniques: time division multi-access (TDMA), frequency division multi-access (FDMA), and direct sequence code division multi-access (DS-CDMA) [6]. In TDMA and FDMA, the interference (called multi-access interference (MAI)) from co-channel users in the same cell limits the transmission quality and therefore, the channel management must be done carefully. On the other hand, DS-CDMA can suppress the MAI by a factor of the spreading factor through the despreading process and thus, can avoid a sophisticated channel management and just assigns a different spreading code to a different user. However, the MAI suppression by the despreading process only is not sufficient. The use of interference cancellation (IC) [7-9] is effective to further suppress the MAI.

Recently, we proposed a per-antenna interference cancellation (PAIC) [10] for DAN using DS-CDMA. In the PAIC, the same number of cancelling users is assumed for all distributed antennas [10]. It should be noted that in a real environment, the user distribution may not be uniform and the number of users connected to a different distributed antenna may be different. This means that the number of users connected to some distributed antenna is more than the number of cancelling users and hence, the interference suppression may not be sufficient. To avoid such a situation, the number of cancelling users needs to be sufficiently a large value, leading to the excessive computational complexity.

In this paper, we propose an adaptive per-antenna interference cancellation (APAIC) which adapts the number of cancelling users to the changing user distribution. Distributed antennas transmit their own pilot signals. Each user selects the received antennas in the descending order of the instantaneous received pilot signal power and reports the user index and the rank of selected antenna to each of selected antennas. In APAIC, each antenna has a user table containing the indices of users

who have selected that antenna and the ranks of that antenna. Each antenna looks up the user table and cancels the users who have selected it higher than the prescribed ranking threshold O_{th} . Figure 1 shows an example of APAIC when there are 2 antennas and five users. The desired user $U_{\#0}$ selects the distributed antenna #1 and #2 as the received antenna while user $U_{\#1}$ uses the distributed antenna #1 and user $U_{\#2}$, $U_{\#3}$, and $U_{\#4}$ use the distributed antenna #2 as the 1st received antenna. In APAIC when $O_{th}=1$, the users who have selected the antenna of interest as the 1st ranking are cancelled. Therefore, in this case, $U_{\#1}$ is cancelled on the distributed antenna #1 while $U_{\#2}$, $U_{\#3}$, and $U_{\#4}$ on the distributed antenna #2 respectively. If a smaller (larger) number of users are located near the distributed antenna of interest, less (more) number of users are selected to be cancelled at that antenna. Hence, the number of users to be cancelled is changed so as to cancel only the users who give dominant MAI. Accordingly, the computational complexity can be reduced while keeping the transmission quality same as the previously proposed non-adaptive PAIC (the number of cancelling users is fixed). We investigate, by computer simulation, the uplink capacity of DS-CDMA DAN using APAIC and show that the APAIC achieves a higher uplink capacity than non-adaptive PAIC in a non-uniform user distribution.

The remainder of this paper is organized as follows. The uplink model of DS-CDMA DAN is presented in Sect. 2. Section 3 proposes the APAIC. The computer simulation results are presented in Sect. 4. Section 5 offers some conclusions.

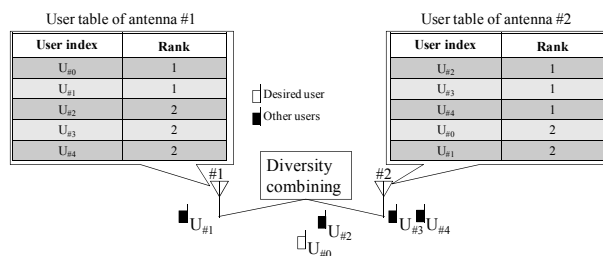


Fig. 1 An example of APAIC.

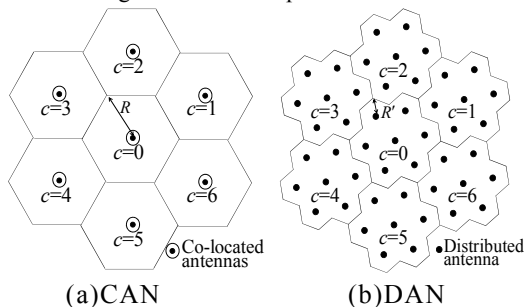


Fig. 2 Network models.

2. DS-CDMA DAN

2.1. DAN Model

In this paper, multi-cell and multi-user environment is considered. Fig. 2 illustrates the models of DAN and CAN with $N_{total}=7$ antennas in a cell. The center cell ($c=0$) is assumed to be the cell of interest. There are 6 strong co-channel interference (CCI) cells at the first tier. 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 in 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 located in each cell and user terminal equips with single transmit antenna (i.e. $N_r=1$). They are accommodated in a cell by DS-CDMA. All antennas transmit their own pilot signals. Each user selects N_r received antennas in the descending order of the instantaneous received pilot signal power from N_{total} antennas and reports the user index and the rank of selected antenna to each of selected antennas.

2.2. Propagation Model

In the following, without loss of generality, we assume that the user in the $c=0$ th cell is the desired user.

The broadband propagation channel is characterized by propagation path loss, shadowing loss, and frequency-selective fading. Assuming a frequency-selective channel composed of L distinct paths, the channel impulse response, $\tilde{h}^{(u,n_r)}(\tau)$, of the link between the u th user and the n_r th distributed antenna can be expressed as

$$\tilde{h}^{(u,n_r)}(\tau) = \sum_{l=0}^{L-1} \tilde{h}_l^{(u,n_r)} \cdot \delta(\tau - \tau_l^{(u,n_r)}), \quad (1)$$

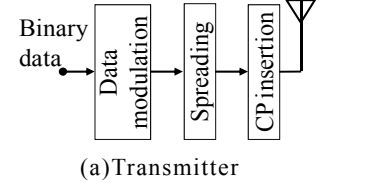
where $\tilde{h}_l^{(u,n_r)}$ is the l th complex valued path gain, including the impact of the propagation path loss and the shadowing loss, of the link between the u th user and the n_r th distributed antenna. It can be expressed as

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

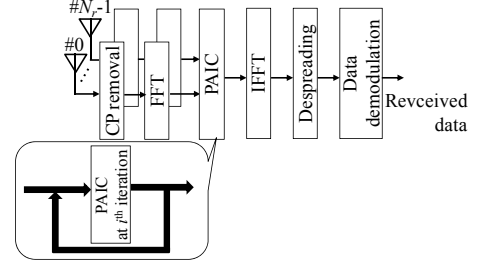
where $D^{(u,n_r)}$ is the distance between the u th user and the n_r th distributed antenna. α denotes the path loss exponent and $\eta^{(u,n_r)}$ is the shadowing loss in dB between the u th user and the n_r th distributed antenna. $g_l^{(u,n_r)}$ and $\tau_l^{(u,n_r)}$ are the l th complex valued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

The instantaneous received signal power at the n_r th distributed antenna from the u th user, $P_r^{(u,n_r)}$, can be expressed as

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



(a) Transmitter



(b) Receiver

Fig. 3 Transmitter/receiver structures.

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

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

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

$$\hat{h}_l^{(u,n_r)} = \sqrt{(D^{(u,n_r)}/R)^{-\alpha}} \cdot 10^{-\frac{\eta^{(u,n_r)}}{10}} \cdot g_l^{(u,n_r)}. \quad (5)$$

3. DS-CDMA using Adaptive PAIC

3.1. Signal Representation

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

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, binary data sequence $\{d^{(u)}(n); n=0, \dots, (N_c/SF-1)\}$, and then spread by multiplexing it with a spreading code sequence $c^{(u)}(t)$. The resultant DS-CDMA signal, $\{\tilde{s}^{(u)}(t); t=0, \dots, (N_c-1)\}$, can be expressed as

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

where

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

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 is the desired user. The n_r th distributed

antenna which is selected by the desired user receives the signal from the all users including desired user in the cell and interference from CCI cells. At the receiver, after the 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 selected by u th user, $\{R^{(u,n_r)}(k); k=0,\dots,(N_c-1)\}$, can be expressed as

$$R^{(u,n_r)}(k) = \sqrt{2P_t^{(u)}} H^{(u,u \rightarrow n_r)}(k) S^{(u)}(k) + \sum_{\substack{u'=0 \\ u' \neq u}}^{U-1} \sqrt{2P_t^{(u')}} H^{(u',u \rightarrow n_r)}(k) S^{(u')}(k) + I^{(u \rightarrow n_r)}(k) + \Pi^{(u \rightarrow n_r)}(k) \quad (8)$$

where $S^{(v)}(k)$ is the k th frequency component of $s^{(v)}(t)$, and $P_t^{(v)}$ is the normalized transmit power of v th user ($v=0,\dots,(U-1)$). $H^{(v',v \rightarrow n_r)}(k)$ denotes the k th frequency channel transfer function between the v' th user and the n_r th received antenna selected by the v th user. $I^{(v \rightarrow n_r)}(k)$ is the CCI component at the n_r th received antenna selected by the v th user having variance $2\sigma_{CCI}^{(v \rightarrow n_r)2}$. $\Pi^{(u \rightarrow n_r)}(k)$ 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. Then, IC is performed to detect the signal of desired user. Finally, the data demodulation is carried out using the time-domain soft decision variance after IC.

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

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

where $h_l^{(v,v \rightarrow n_r)}$ 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.

3.2. Adaptive PAIC

In this paper, we assume parallel interference cancellation (PIC) [7]. The structure of the i th cancellation stage in PIC is illustrated in Fig. 4. Each stage consists of MMSE-FDE, interference cancellation, diversity combining, inverse FFT (IFFT), despreading, and replica generation.

(a) $i=0$ th stage

First, at the $i=0$ th stage, MMSE-FDE and the diversity combining are carried out. The received signal after diversity combining is given as

$$\hat{R}^{(u)}(k) = \sum_{n_r=0}^{N_r-1} W_0^{(u,n_r)}(k) R^{(u,n_r)}(k) \quad (10)$$

where $W_0^{(u,n_r)}(k)$ is MMSE-FDE weight. This MMSE-FDE weight is determined so as to minimize the mean square error (MSE) 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

$$W_0^{(u,n_r)}(k) = \frac{P_t^{(u)} H^{(u,u \rightarrow n_r)*}(k)}{\left[\begin{array}{l} P_t^{(u)} |H^{(u,u \rightarrow n_r)}(k)|^2 \\ + \sum_{\substack{u'=0 \\ u' \neq u}}^{U-1} P_t^{(u')} |H^{(u',u \rightarrow n_r)}(k)|^2 \\ + \sigma_{CCI}^{(u \rightarrow n_r)2} + \frac{N_0}{T_c} \end{array} \right]} \quad (11)$$

After the diversity combining, the frequency-domain received signal is transformed by N_c -point IFFT into the time-domain signal. Then, despreading is carried out to obtain the soft decision variance.

(b) $i=1,\dots,(I-1)$ th stage

At $i=1,\dots,(I-1)$ th stage, after MMSE-FDE and the diversity combining, the residual inter-chip interference replica and MAI replica, which are generated using the log-likelihood ratio (LLR) at $(i-1)$ th stage, are subtracted from the received signal. In APAIC, each antenna has a user table containing the indices of users who have selected that antenna as the received antenna and the ranks of that antenna. For example, when some users consider a distributed antenna as the n_r th received antenna, the ranks of these users are n_r in the user table of that antenna. Each antenna looks up the user table and cancels the users who have selected it higher than the prescribed ranking threshold O_{th} .

The received signal after interference cancellation in APAIC is given as

$$\hat{S}_i^{(u)}(k) = \sum_{n_r=0}^{N_r-1} \left[\begin{array}{l} W_i^{(u,n_r)}(k) R^{(u,n_r)}(k) \\ - M_i^{(u,n_r,u)}(k) \bar{S}_{i-1}^{(u)}(k) \\ - \sum_{u_c \in X_{(u,n_r,O_{th})}} M_i^{(u,n_r,u_c)}(k) \bar{S}_{i-1}^{(u_c)}(k) \end{array} \right] \quad (12)$$

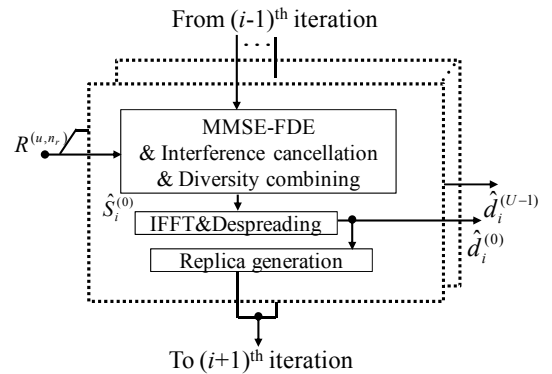


Fig. 4 PIC structure.

where $X_{(u,n_r,O_h)}$ denotes the set of users who have been determined as the cancelling users for the n_r th antenna selected by the u th user. $\bar{S}_{i-1}^{(v)}(k)$ is the frequency-domain transmit signal replica of the v th user at the $(i-1)$ th stage. This replica is given as

$$\begin{aligned} \bar{S}_{i-1}^{(v)}(k) &= \sum_{t=0}^{N_c-1} \left\{ \bar{s}_{i-1}^{(v)}(t) \right\} \exp\left(-j2\pi k \frac{t}{N_c}\right), \quad (13) \\ &= \sum_{t=0}^{N_c-1} \left\{ \sqrt{2P_t^{(v)}} \bar{d}_{i-1}^{(v)}(t/SF) c^{(v)}(t) \right\} \exp\left(-j2\pi k \frac{t}{N_c}\right) \end{aligned}$$

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

$$\begin{aligned} W_i^{(u,n_r)}(k) &= \frac{P_t^{(u)} H^{(u,u \rightarrow n_r)}(k)}{\left[\begin{aligned} &P_t^{(u)} \rho_{i-1}^{(u)} |H^{(u,u \rightarrow n_r)}(k)|^2 \\ &+ \sum_{\substack{u_c \in X_{(u,n_r,O_h)}}} P_t^{(u_c)} \rho_{i-1}^{(u_c)} |H^{(u_c,u \rightarrow n_r)}(k)|^2 \\ &+ \sum_{\substack{u_c \in X_{(u,n_r,O_h)}}} P_t^{(u_c)} |H^{(u_c,u \rightarrow n_r)}(k)|^2 \\ &+ \sigma_{CCI}^{(u \rightarrow n_r)} + \frac{N_0}{T_c} \end{aligned} \right]}, \quad (14) \\ M_i^{(u,n_r,v)}(k) &= \begin{cases} W_i^{(u,n_r)}(k) H^{(u,u \rightarrow n_r)}(k) \\ -\frac{1}{N_c} \sum_{k=0}^{N_c-1} W_i^{(u,n_r)}(k) H^{(u,u \rightarrow n_r)}(k) & \text{if } v=u \\ W_i^{(u,n_r)}(k) H^{(v,u \rightarrow n_r)}(k) & \text{otherwise} \end{cases}, \quad (15) \end{aligned}$$

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

$$\rho_{i-1}^{(v)} = \frac{1}{N_c} \sum_{t=0}^{N_c-1} \left[1 - (2P_t^{(v)})^{-1} |\bar{s}_{i-1}^{(v)}(t)|^2 \right]. \quad (16)$$

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

On the other hand, in the conventional PAIC, the number U_c of users to be cancelled is the same among all distributed antennas. Therefore, the conventional PAIC cannot adapt to the non-uniform user distribution. The signal representation of the conventional PAIC is shown in Appendix.

4. Computer Simulation

The simulation conditions are summarized in Table 1. QPSK data modulation is considered. FFT block size N_c and CP length N_g are respectively set to $N_c=256$ and $N_g=32$. Long PN sequence is used as the spreading code and spreading factor SF is set to $SF=16$. 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 standard deviation of the

log-normally distributed shadowing loss σ are assumed to be $\alpha=3.5$ and $\sigma=7.0$ dB, respectively. The number of antennas in a cell N_{total} and received antennas N_r are assumed $N_{total}=7$ and $N_r=3$. We assume the interference-limited channel ($SNR_{target} \gg 1$) and ideal TPC. Perfect channel estimation is also assumed. The number of iterations of IC is set to $I=6$.

We also assumed that users are intensively located in the hexagonal area covered by the certain distributed antenna in the cell of interest with probability $\kappa/(\kappa+6)$, where κ is the user distribution factor. When $\kappa=1$, all users are uniformly located in the cell. In this paper, we assume two case: case-I and case-II that many users are concentrated in the center distributed antenna and another distributed antenna excluding the center antenna, respectively. Note that the users in CCI cells are assumed to be uniformly located in each cell. As an example, we show the probability that the user is located in that hexagonal area covered by each distributed antenna when $\kappa=6$ in Fig. 5. When $\kappa=6$, the probability that users are intensively located in the hexagonal area covered by the certain distributed antenna is 1/2, while in the area covered by the other distributed antenna is 1/12.

In this paper, we define the uplink capacity as follows. At first, the outage probability is defined as the probability that the local average bit error rate (BER) exceeds the required BER. Then, the uplink capacity is defined as the maximum number of users keeping the outage probability below the allowable outage probability Q . In this paper, the required BER and the allowable outage probability Q are set to 10^{-2} and $Q=0.1$, respectively.

Fig. 6 shows the outage probability as a function of the number of users per cell U in DS-CDMA DAN with APAIC when $N_r=3$ and $\kappa=1$. For comparison, no interference cancellation case and full interference cancellation case that all interfering users in a cell are cancelled are also plotted. It is shown in Fig. 6 that applying IC can achieve lower outage probability due to suppressing MAI. Furthermore, the improvement effect of IC in DAN is larger than in 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 IC is negligible because IC cannot operate normally due to low accuracy of chip replica. In CAN, the received signal-to-interference power ratio (SIR) degrades because antennas are co-located and hence, the improvement effect of IC is very small due to low accuracy of chip replica. On the other hand, in DAN, high received SIR can be obtained because user can find nearby antenna with high probability. Therefore, in DAN, accuracy of chip replica is high and hence, the improvement effect of IC is large. It is shown in Fig. 6 that the uplink capacity of DS-CDMA DAN with APAIC ($O_{th}=3$) is 16 which is 16times higher than that of CAN.

Fig. 7 shows the uplink capacity as a function of the

user distribution factor κ in DAN. It is shown in Fig. 7 that APAIC can achieve a higher uplink capacity than conventional non-adaptive PAIC. This is because that MAI can be sufficiently suppressed by changing the number of users to be cancelled to adapt to the user distribution even if many users are intensively located in the certain area. It is also in Fig. 7 that in case-I that many users are concentrated in the area covered by the center distributed antenna, the uplink capacity increases as κ increases while the uplink capacity decreases in case-II that users are concentrated in the area covered by the cell edge distributed antenna. The reason for this is given below. The impact of CCI becomes small as user comes to the center of the cell due to the propagation path loss. Therefore, in case-I ($\kappa > 1$), the impact of CCI gets smaller as κ increases and as consequence, the uplink capacity increases. On the other hand, in case-II, the impact of CCI gets larger as κ increases and as consequence, the uplink capacity decreases in case-II.

Fig. 8 shows the probability distribution of the number of cancelling users in DS-CDMA DAN with APAIC ($O_{th}=1$) to achieve $U_{max}=15$ in the case-I ($\kappa=6$). It is shown in Fig. 8 that many users are cancelled on the distributed antenna whose coverage area has many users while the number of cancelling users is few on other distributed antennas. The average number of cancelling users is 5.3 on the center distributed antenna while 1.5 on each other distributed antennas. The sufficient number of users to be cancelled is 5 in the conventional non-adaptive PAIC to achieve the same uplink capacity $U_{max}=15$. Therefore, APAIC can reduce the number of cancelling users on the distributed antenna whose area is depopulated compared to conventional non-adaptive PAIC.

5. Conclusion

In this paper, we proposed APAIC to adapt to the user-distribution and change the number of users to be cancelled. We showed by computer simulation that APAIC can achieve a higher uplink capacity than conventional non-adaptive PAIC to change the number of users to be cancelled even if the user distribution is not uniform. It was also showed that in case-I ($\kappa=6$) that many users are concentrated in the area covered by the center antenna in the cell, APAIC ($O_{th}=1$) can reduce the average number of cancelling users in antenna which is used few users to 1.5 compared to conventional non-adaptive PAIC which needs $U_c=5$ to achieve the same uplink capacity $U_{max}=15$.

Table 1 Simulation conditions.

Transmitter	Modulation	QPSK
	No. of FFT points	$N_c=256$
	Guard interval length	$N_g=32$
	Spreading factor	$SF=16$
	Spreading codes	Long PN code
	SNR-based fast TPC	$SNR_{target} \gg 1$
Channel	Fading	Frequency-selective block Rayleigh
	Power delay profile	$L=16$ -path uniform power delay profile
	Time delay	$\tau_l=l$ ($l=0 \sim L-1$)
	Path loss exponent	$\alpha=3.5$
	Standard deviation of shadowing loss	$\sigma=7.0$ dB
Receiver	No. of antennas in a cell	$N_{total}=7$
	No. of received antennas	$N_r=3$
	Channel estimation	Ideal
Required quality	Required BER	10^{-2}
	Allowable outage probability	$Q=0.1$

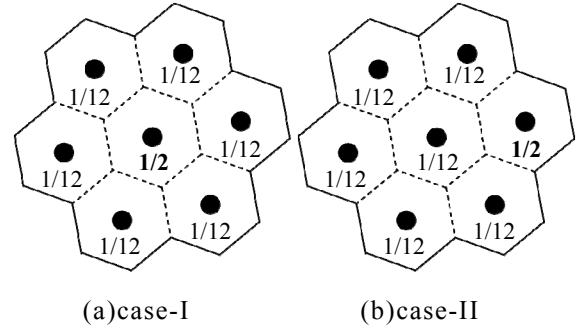


Fig. 5 An example of a non-uniform user distribution ($\kappa=6$).

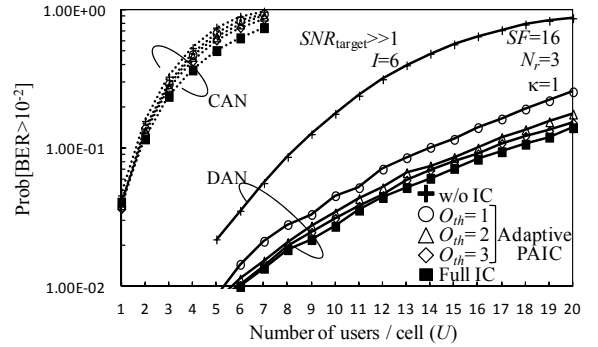
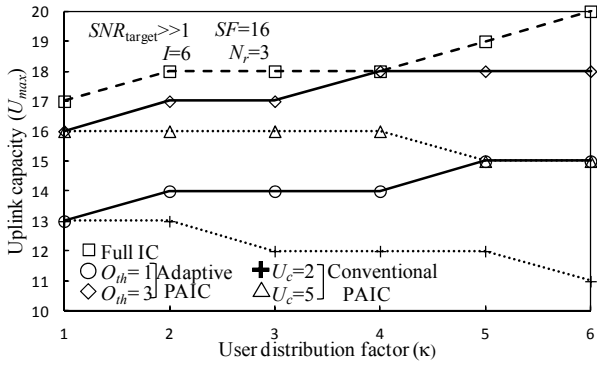
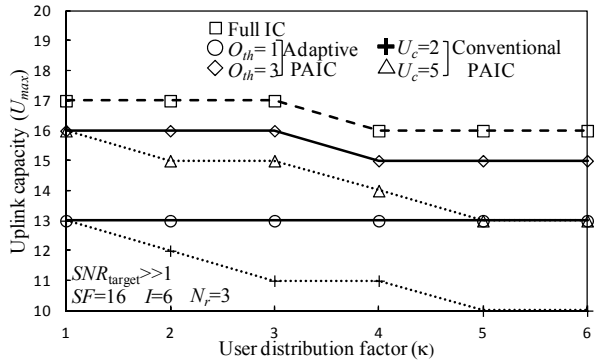


Fig. 6 Outage probability ($\kappa=1$).



(a) case-I



(b) case-II

Fig. 7 Uplink capacity.

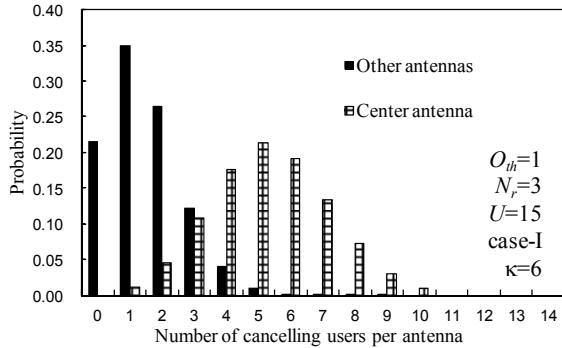


Fig. 8 Probability distribution of the number of cancelling users.

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Appendix

Previously proposed PAIC

In the conventional PAIC, at first, interfering users on each distributed antenna are sorted in the descending order of the instantaneous received power. Then, U_c users having the highest received powers are selected on each distributed antenna to be cancelled. The received signal after interference cancellation is given as

$$\hat{S}_i^{(u)}(k) = \sum_{n_r=0}^{N_r-1} \begin{bmatrix} W_i^{(u,n_r)}(k) R^{(u,n_r)}(k) \\ -M_i^{(u,n_r,u)}(k) \bar{S}_{i-1}^{(u)}(k) \\ -\sum_{u_c=0}^{U_c-1} M_i^{(u,n_r,f_{PAIC}(u,n_r,u_c))}(k) \bar{S}_{i-1}^{(f_{PAIC}(u,n_r,u_c))}(k) \end{bmatrix}. \quad (A1)$$

MMSE-FDE weight $W_i^{(u,n_r)}(k)$ is given as

$$W_i^{(u,n_r)}(k) = \frac{P_i^{(u)} H^{(u,u \rightarrow n_r)}(k)}{\begin{bmatrix} P_t^{(u)} \rho_{i-1}^{(u)} |H^{(u,u \rightarrow n_r)}(k)|^2 \\ + \sum_{u_c=0}^{U_c-1} P_t^{(f_{PAIC}(u,n_r,u_c))} \rho_{i-1}^{(f_{PAIC}(u,n_r,u_c))} |H^{(f_{PAIC}(u,n_r,u_c),u \rightarrow n_r)}(k)|^2 \\ + \sum_{u_c=U_c}^{U-2} P_t^{(f_{PAIC}(u,n_r,u_c))} |H^{(f_{PAIC}(u,n_r,u_c),u \rightarrow n_r)}(k)|^2 \\ + \sigma_{CCI}^{(u \rightarrow n_r)^2} + \frac{N_0}{T_c} \end{bmatrix}}. \quad (A2)$$

The function $f_{PAIC}(u,n_r,u_c)$ ($f_{PAIC}(u,n_r,u_c)=0, \dots, u-1, u+1, \dots, U-1$) denotes the user who has the u_c th highest received power at the n_r th received antenna selected by the u th user. The instantaneous received power of v th user at the n_r th antenna used by u th user, $\Gamma_{PAIC}^{(u,n_r,v)}$, is given as

$$\Gamma_{PAIC}^{(u,n_r,v)} = \sum_{k=0}^{N_c-1} 2P_t^{(v)} |H^{(v,u \rightarrow n_r)}(k)|^2. \quad (A3)$$