A Dynamic Channel Assignment Scheme for Distributed Antenna Networks

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Abstract— **In this paper, we propose a dynamic channel assignment (DCA) scheme for distributed antenna networks (DANs). DANs, in which many antennas are distributed in each cell, significantly reduce the transmit power compared to conventional cellular networks (CNs). In DAN, a different group of channels should be assigned for each distributed antenna to avoid the interference. Since DAN can also reduce the interference power due to its low transmit power property, the same channel groups can be reused even within the same cell. Proposed DCA scheme dynamically assigns the channels based on the co-channel interference measurement. Computer simulation results demonstrate that the DAN using proposed DCA achieves higher spectrum efficiency than the conventional CN.**

Keywords- distributed antenna, frequency reuse, dynamic channel assignment

I. INTRODUCTION

In the next generation of mobile communication services, very high data rate transmissions are demanded. However, the transmission quality of conventional cellular networks (CNs) degrades due to path loss, shadowing loss, and fading. Antenna diversity [1]-[3] is one of the powerful techniques to mitigate the effect of fading. However, in the conventional CNs, diversity antennas are co-located at the same location, i.e., base station (BS), and therefore, the negative impact of the path and shadowing losses cannot be eliminated [4],[5]. The performance degradation is significant when a mobile terminal (MT) is near the cell edge and therefore, the transmit power should be increased in the CN. Distributed antenna network (DAN), in which many antennas are distributed in each cell, has been attracting much attention [6-10]. Figure 1 illustrates the conceptual model of DAN. In DAN, some distributed antennas close to an MT are selected to serve the MT. Therefore, the received signal power significantly increases and the required transmit power can be kept low [10].

In DAN, a different group of channels should be assigned for adjacent distributed antenna so as to avoid the interference. However, due to the low transmit power property of the DAN, the interference power can be also reduced. Therefore, the same channel can be reused even within the same cell. In general, channel assignment schemes are classified in two groups: fixed channel assignment (FCA) [11] and dynamic channel assignment (DCA) [12-14]. FCA may not be suitable to the DAN since the co-channel interference dynamically changes according to the co-channel users' movements. In this paper, we consider DCA scheme. In Ref. [14], a DCA scheme using channel segregation (CS) algorithm (called CS-DCA in this paper) was proposed for a cellular system. In the CS-DCA, the priority order of each channel is stored in a priority table at each base station (BS). When the channel is requested, the channel having the highest priority among idle channels is assigned. The priority is updated by measuring the signal-to-interference plus noise power ratio (SINR) every time when the channel is requested; the priority of a channel is increased if the SINR of that channel exceeds the threshold, otherwise the priority is decreased. In this way, the same channel can be reused in different BSs, depending on the average traffic distribution.

In this paper, we modify the CS-DCA for its application to DAN. In the DAN using the modified CS-DCA, the priority table is attached to each distributed antenna. The priority of a channel at each antenna is determined by the average received CCI power (which is computed using the past CCI measurements). Using the modified CS-DCA, the same channel can be reused even within a cell. The DAN using the modified CS-DCA can achieve much higher spectrum efficiency than the conventional CN.

The reminder of the paper is organized as follows. Section II describes the modified CS-DCA scheme. Section III derives a channel capacity expression for the downlink transmission. In Section IV, the average user capacity and the average cell capacity when using the modified CS-DCA are evaluated by computer simulation. Section V offers some conclusions and a future work.

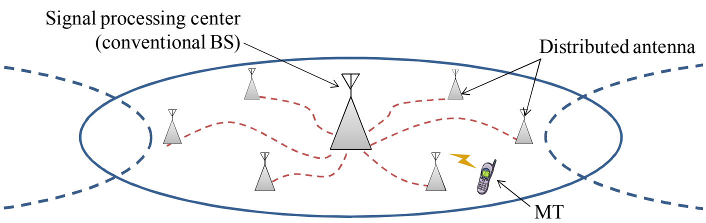


Figure 1. Conceptual structure of DAN.

II. MODIFIED CS-DCA

In this paper, frequency-division multiple-access (FDMA) system is considered. The number of available channels is denoted by N_{ch}. It is assumed that when an MT requests a transmission, a distributed antenna which is the closest to the MT is selected among N_{total} distributed antennas. Figure 2 shows a flowchart of the modified CS-DCA. The modified CS-DCA periodically measures the average interference powers on all available channels at each distributed antenna and stores the measured average CCI powers in the CCI table attached to each antenna. When the channel is requested, the channel having the lowest average CCI power among idle channels is assigned. Using the modified CS-DCA to the DAN, the same channel can be reused within a cell and hence, the spectrum efficiency significantly improves compared to the CN. Below, assuming that the n-th distributed antenna (n=0~ N_{total}−1) is selected, we will explain the CCI table updating and the channel assignment.

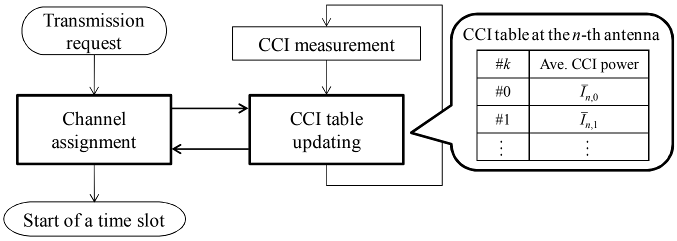


Figure 2. Flowchart of CCI table updating for modified CS-DCA.

A. CCI table updating

The modified CS-DCA measures the average CCI power for all available channels at each antenna. The first order filtering is assumed for the average CCI power measurement. The average CCI power $\bar{I}_{n,k}(t)$ on the k-th channel (k=0~ N_{ch}−1) at time t at the n-th distributed antenna is given as

$$\bar{I}_{n,k}(t) = \beta \cdot \bar{I}_{n,k}(t-1) + (1-\beta) \cdot I_{n,k}(t), \tag{1}$$

where $I_{n,k}(t)$ and β (0≤ β<1) are respectively the instantaneous CCI power at time t and the filter forgetting factor. The traffic changes from time to time and the instantaneous CCI power also varies in time. If too small β is used, the CCI measurement interval becomes too short and hence, the channel assignment cannot be stable.

B. Channel assignment algorithm

The n-th antenna is assumed to be selected. Figure 3 shows a flowchart of the channel assignment. When the channel is requested at time t, the modified CS-DCA checks the CCI table attached to the n-th antenna and assigns the k_n-th channel having the lowest average CCI power among the idle channels, where k_n is given as

$$k_n = \underset{k \in A_n(t)}{\arg\min} \left\{ \bar{I}_{n,k}(t-1) \right\} \tag{2}$$

with $A_n(t)$ representing a set of the idle channels at time t for the n-th antenna. If no channel is idle, the channel assignment fails and an MT which has requested a channel cannot receive data.

Figure 4 shows an example of the channel priority distribution when using the modified CS-DCA with N_{ch}=3. The channels for each distributed antenna are shown from the left to right in an ascending order of the average CCI power. It can be understood from Fig. 4 that the same channel can be reused within the same cell. This leads to the improved spectrum efficiency compared to the CN.

The modified CS-DCA can also be applied to the CN, where each BS is assumed to be equipped with the same number of antennas as DAN. In the CN, the average CCI power sum of all antennas is measured to update the CCI table.

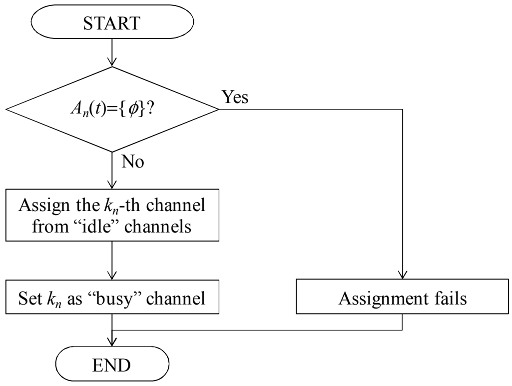


Figure 3. Flowchart of channel assignment at the n-th antenna.

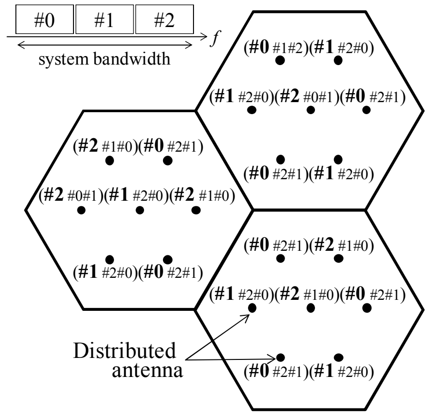


Figure 4. An example of channel priority distribution for modified CS-DCA with N_{ch}=3.

III. CHANNEL CAPACITY EXPRESSION

In this paper, we assume a frequency- nonselective fading channel and consider the downlink transmission using maximal ratio transmission (MRT) [1]. An MT is assumed to be equipped with single antenna. The cell of interest is denoted by d=0. There are $U(d)$ active MTs in the d-th cell. Assuming slotted packet transmissions, each active MT requests transmission of a packet with a probability of p. When an MT requests a transmission, one distributed antenna is selected among N_{total} distributed antennas in a cell.

Assuming that the $n(0)$-th distributed antenna is selected, the lowpass equivalent transmit signal for the $u(0)$-th MT is expressed as

$$s_{u(0)} = \sqrt{2P_t}\, w_{u(0)} \cdot x_{u(0)}, \tag{3}$$

where $x_{u(0)}$ and P_t represents the data symbol and the total transmit power for each cell, respectively. $w_{u(0)}$ is the MRT weight, given as [1]

$$w_{u(0)} = \frac{h^*_{n(0),u(0)}}{\sqrt{\sum_{u(0)=0}^{U(0)-1} \left|h_{n(0),u(0)}\right|^2}}, \tag{4}$$

where $h_{n(0),u(0)}$ represents the channel gain between the $n(0)$-th distributed antenna and the $u(0)$-th MT of the cell of interest (d=0). $U(0)$ represents the number of active users in the cell of interest. The received signal at the $u(0)$-th MT is expressed as

$$\begin{aligned} y_{u(0)} &= h_{n(0),u(0)} s_{u(0)} + \sum_{d=1}^{\infty} \sum_{u(d)=0}^{U(d)-1} \varepsilon_{u(0),u(d)} \delta_{u(d)} h_{n(0),u(d)} s_{u(d)} + n_{u(0)} \\ &= \left(\sqrt{2P_t} \left|h_{n(0),u(0)}\right|^2 \Big/ \sqrt{\sum_{u(0)=0}^{U(0)-1} \left|h_{n(0),u(0)}\right|^2} \right) \cdot d_{u(0)} \\ &\quad + \sqrt{2P_t} \sum_{d=1}^{\infty} \sum_{u(d)=0}^{U(d)-1} \varepsilon_{u(0),u(d)} \delta_{u(d)} h_{n(0),u(d)} s_{u(d)} + z_{u(0)} \end{aligned}, \tag{5}$$

where the first, second, and third terms are the desired signal, the co-channel interference (CCI), and the noise, respectively. $h_{n(0),u(d)}$ is the channel gain between the $n(d)$-th distributed antenna in the d-th cell and the $u(0)$-th MT of the cell of interest. $\varepsilon_{u(0),u(d)}$=1 when the same channel is used for the $u(0)$-th user and $u(d)$-th user; otherwise $\varepsilon_{u(0),u(d)}$=0. $\delta_{u(d)}$ represents whether the $u(d)$-th MT requests a transmission or not; $\delta_{u(d)}$=1 when the $u(d)$-th MT requests the transmission, otherwise $\delta_{u(d)}$=0. $z_{u(0)}$ is the complex-valued noise having zero mean and variance $2N_0/T_s$ with N_0 and T_s being the single-sided power spectrum density of additive white Gaussian noise (AWGN) and the symbol length, respectively. The instantaneous SINR is given as

$$SINR_u = \frac{\left(\left|h_{n(0),u(0)}\right|^2\right)^2 \Big/ \sum_{u=0}^{U(0)-1} \left|h_{n(0),u(0)}\right|^2}{\sum_{d=1}^{\infty} \sum_{u(d)=0}^{U(d)-1} \varepsilon_{u(0),u(d)} \delta_{u(d)} \left|h_{n(0),u(d)} w_{u(d)}\right|^2 + \left(\frac{E_s}{N_0}\right)^{-1}}, \tag{6}$$

where $E_s=P_t \cdot T_s$ represents the symbol energy. The channel capacity of the $u(0)$-th MT is given by

$$C_{u(0)} = \frac{p}{N_{ch}} \log_2\left(1 + SINR_{u(0)}\right). \tag{7}$$

In the case of CN, all the N_{total} antennas which are co-located at the BS are used for the transmission using MRT.

IV. PERFORMANCE EVALUATION

A. Simulation condition

Table I summarizes the simulation condition. Figure 5 illustrates the cellular model. D=37 cells are considered in the simulation. The cell of interest for the evaluation of the channel capacity is the 0-th cell (d=0). Figure 6 illustrates the antenna distributions of the DAN and the CN. The cell radius is denoted by R. N_{total}=7 distributed antennas are equidistantly located along the circle of the radius (2/3)R in the DAN case while they are co-located at BS in the CN case. The total number of channels is assumed to be N_{ch}=7. As assumed in Sec. III, we assume a frequency- nonselective Rayleigh fading channel. The propagation channel assumed is characterized by distance-dependent path loss with path loss exponent α=3.5, log-normally distributed shadowing loss with zero-mean and standard deviation σ=7.0, and fading.

In the simulation, U active MTs are randomly generated in each cell (i.e., $U(d)=U$ for d=0~36), and each MT requests the channel with an equal probability of p. In the DAN, the distributed antenna which is the closest to the MT is selected and the channel having the highest priority in the CCI table attached to that antenna is used for the transmission. The average capacity is calculated assuming the interference limited channel.

Table I. Simulation condition.

System	No. of co-channel cells	$D = 37$
	No. of channels	$N_{ch} = 7$
	No. of antennas in a cell	$N_{total} = 7$
	Transmission prob.	$p = 0.2 \sim 1.0$
	Channel estimation	Ideal
DCA	Forgetting factor of first order filtering	$\beta = 0.1 \sim 0.99$
Channel	Fading	Frequency-nonselective block Rayleigh
	Shadowing loss standard deviation	$\sigma = 7.0$
	Path loss exponent	$\alpha = 3.5$
	Transmit E_s/N_0	∞ (interference limited)

The channel gain $h_{n(0),u(0)}$ in Eq. (5) can be expressed as

$$h_{n(0),u(0)} = \sqrt{R_{n(0),u(0)}^{-\alpha} \cdot 10^{-\frac{\eta_{n(0),u(0)}}{10}}} \cdot g_{n(0),u(0)}, \tag{8}$$

where $R_{n(0),u(0)}$ and $\eta_{n(0),u(0)}$ are respectively the distance between $u(0)$-th MT of the d-th cell and $n(0)$-th distributed antenna of the 0-th cell and the log-normally distributed shadowing loss of zero-mean and standard deviation σ. $g_{n(0),u(0)}$ represents the complex-valued fading gain. The instantaneous received signal power $P_{r,u(0)}$ at the $u(0)$-th MT from $n(0)$-th distributed antenna is given as

$$\begin{aligned} P_{r,u(0)} &= P_{t,u} \cdot R_{n(0),u(0)}^{-\alpha} \cdot 10^{-\frac{\eta_{n(0),u(0)}}{10}} \cdot \left|h_{n(0),u(0)}\right|^2 \\ &= p_{t,u} \cdot r_{n(0),u(0)}^{-\alpha} \cdot 10^{-\frac{\eta_{n(0),u(0)}}{10}} \cdot \left|h_{n(0),u(0)}\right|^2 \end{aligned}, \tag{9}$$

where $p_{t,u(0)}=P_{t,u(0)} \cdot R^{-\alpha}$ and $r_{n(0),u(d)}=R_{n(0),u(d)}/R$ are the normalized transmit power and the normalized distance, respectively.

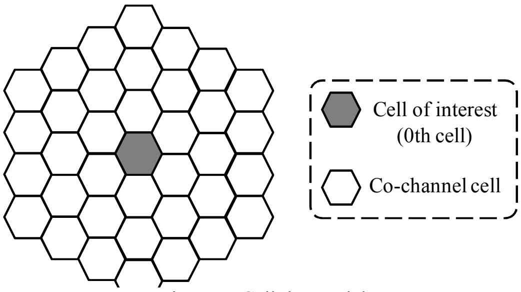
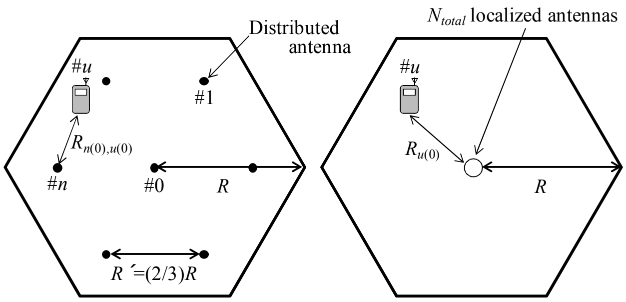


Figure 5. Cellular model.



(a) DAN (b) CN
Figure 6. Antenna distribution pattern.

B. *Optimization of β*

Figure 7 plots the average cell capacity, as a function of the filter forgetting factor β with p as a parameter. The simulation result confirms that the capacity degrades as smaller β is used since the channel priority tends to change randomly. The capacity increases as β approaches 1. However, if β=1 is used, tracking ability against the variations in traffic distribution degrades (in the real environment, the traffic distribution slowly changes in time). Therefore, β=0.99 is used in this paper (CS-DCA with β=0.99 can track against traffic variations having periods of above 100 slots).

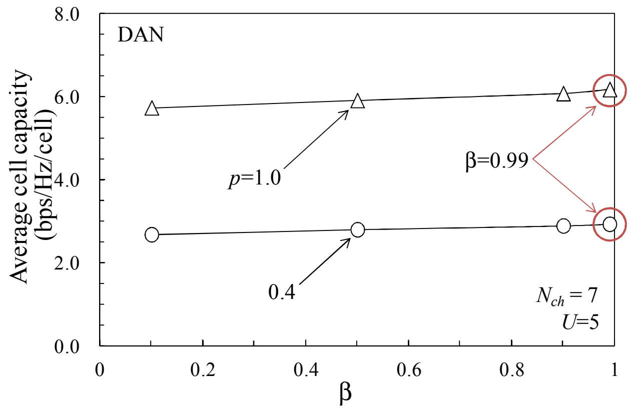
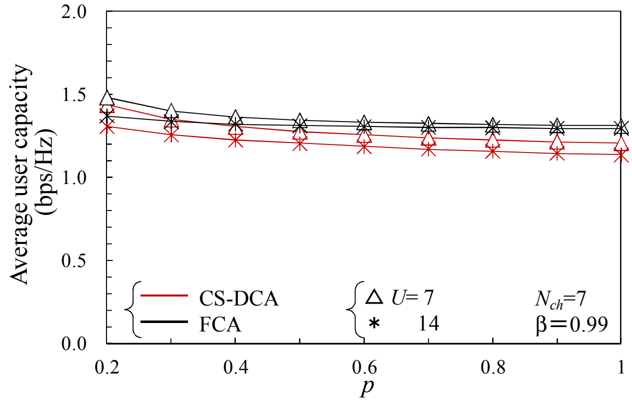


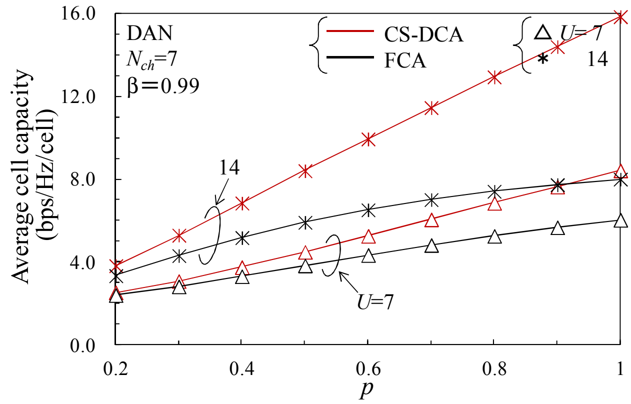
Figure 7. Impact of filter forgetting factor β.

C. *Comparison between modified CS-DCA and FCA*

The modified CS-DCA and FCA in the DAN are compared in terms of average capacity when N_{ch}=N_{total}=7. In the case of the FCA, only one channel is assumed to be available at each distributed antenna so that the CCI on each distributed antenna is minimized. Figure 8 plots the average user capacity and the average cell capacity achievable with the modified CS-DCA and the FCA. It is seen from Fig. 8 that the modified CS-DCA provides higher cell capacity (about 2 times higher average cell capacity when p=1.0) while providing only slightly lower user capacity.



(a) Average user capacity



(b) Average cell capacity
Figure 8. Comparison between modified CS-DCA and FCA.

D. *Comparison between DAN and CN*

The DAN and the CN are compared in Fig. 9, both using modified CS-DCA, in terms of the average cell capacity. It is seen from Fig. 9 that the DAN achieves higher capacity than the CN. In the DAN, an antenna closest to an MT is always selected and hence, the effect of path loss can significantly be reduced. However, in the CN, although MRT diversity using 7 antennas is used, it cannot mitigate the path loss effect since all antennas suffer from the same path loss and hence, the capacity of a user close to the cell edge drops.

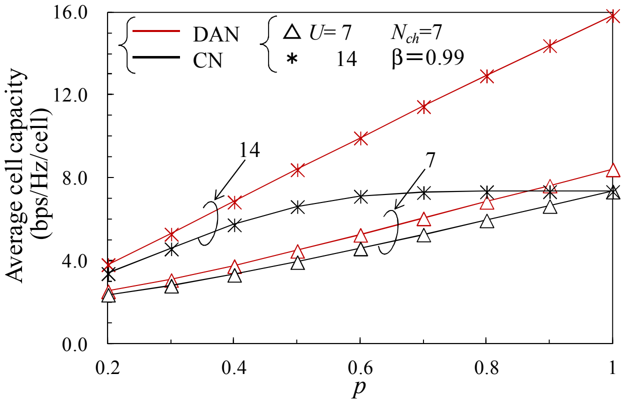


Figure 9. Comparison between DAN and CN, both using modified CS-DCA.

V. Conclusions

In this paper, the modified CS-DCA for DAN was presented. The modified CS-DCA computes the average CCI power for all available channels periodically and updates the CCI table attached to each distributed antenna. Prior to every transmission, the distributed antenna closest to a user is selected and the CCI table attached to the selected antenna is checked to assign the channel having low CCI power. Simulation results confirmed that the modified CS-DCA achieves higher cell capacity than the FCA and that the DAN provides significantly higher cell capacity than the CN when both use the modified CS-DCA.

In this paper, it was assumed that the single distributed antenna is always selected. DCA scheme using multiple distributed antennas is our important topic to study in future.

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