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AP Grouping and Interference-Aware Channel Segregation Based Dynamic Channel Assignment for AP Cooperative Diversity

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Abstract Recently, we proposed interference-aware channel segregation based dynamic channel assignment (IACS-DCA) which selects a channel with low co-channel interference (CCI) by using channel priority table. The transmission performance of a wireless station (STA) located far from access points (APs) degrades due to path loss and shadowing loss. Cooperative diversity is well known to improve the transmission performance. However, an introduction of AP cooperative diversity to IACS-DCA is not easy because different channels are assigned to different APs located nearby each other. In this paper, we propose AP grouping for AP cooperative diversity in a wireless network using IACS-DCA. AP grouping is done based on channel priority table of each AP. By computer simulation, we show that the AP cooperative diversity can improve the transmission performance of IACS-DCA.

Keywords AP cooperative diversity, AP grouping, Channel segregation, Dynamic channel assignment, Co-channel interference

1. Introduction

The number of channels available for wireless networks is limited, and therefore, the same channel needs to be reused by spatially separated access points (APs) or base stations (BSs). Since the co-channel interference (CCI) limits the network capacity, the channels must be reused while minimizing the CCIs received at all APs or BSs. In order to mitigate the CCI problem, we recently proposed interference-aware channel segregation based dynamic channel assignment (IACS-DCA) [1]. In IACS-DCA, each AP periodically measures the instantaneous CCIs on all available channels, computes the average CCI levels using the past CCI measurement results, updates the priority table, and selects the channel with the lowest average CCI power (i.e., channel with the highest priority). It was shown in [2] that IACS-DCA can form a stable channel reuse pattern in a distributed manner.

However, the transmission performance of a wireless station (STA) located far from APs degrades due to path loss and shadowing loss. To solve this problem, AP cooperative diversity using space-time transmit diversity, which uses a group of multiple APs to support an STA, was studied [3]. The cooperating APs in a group use the same channel. However, the introduction of the AP cooperative diversity to IACS-DCA is not easy because different channels are allocated to different APs located nearby each other.

In this paper, we propose AP grouping algorithm for AP cooperative diversity in a wireless network using IACS-DCA. All APs update their own channel priority tables based on their CCI measurement results and inform the channel priority table information to a control center (CC) which decides AP grouping and channel selection. Since CC prioritizes requesting STAs, decides AP grouping and channel selection in the order from the highest-priority STA to the lowest-priority STA, there is a probability that the channel selected for AP(s) in STA's group has already been selected for another STA's group. The worst case for an STA happens when all channels of APs in its group have been selected, i.e., the transmission is blocked.

The rest of the paper is organized as follows. Details of IACS-DCA and the proposed AP grouping algorithm are described in Section 2. In Section 3, we examine the blocking probability, diversity order, and SIR performance of the algorithm evaluated by computer simulation. Section 4 concludes the paper.

2. AP grouping for AP cooperative diversity in a wireless network using IACS-DCA

The overview of AP grouping algorithm for AP cooperative diversity in a wireless network using IACS-DCA is shown in Fig. 1. Each AP updates the channel priority table based on the measurement of beacon signal received from other APs. The CC performs the AP grouping and channel assignment based on channel priority table of each AP. Fig. 2(a), (b) and (c) shows the flowcharts of proposed AP grouping algorithm on AP, STA, and CC, respectively. The details of each algorithm are explained in the following.

2.1. Channel priority table update on AP

In this paper, we utilize a beacon signal transmitted periodically by each AP, for the measurement of instantaneous CCI power. As shown in Fig. 2 (a), each AP 1-1) measures instantaneous received beacon signal power at every time period (this is so-called timeslot) from other APs on all available channels, 1-2) computes the average beacon signal power based on the past beacon signal power measurement results, and 1-3) updates the channel priority table. The channels are listed with the descending priority order (i.e., increasing order of CCI power). To compute the average received beacon signal power on all available channels, the first order filtering [4] is used. The average beacon signal power received at m-th AP on its c-th channel at timeslot t is expressed as

$$\begin{aligned}\bar{I}_m^{(c)}(t) &= (1-\beta)\cdot I_m^{(c)}(t) + \beta\cdot \bar{I}_m^{(c)}(t-1) \\ &= (1-\beta)\cdot\sum_{n=0}^{t}\beta^n I_m^{(c)}(t-n)\end{aligned}, \quad (1)$$

where $I_m^{(c)}(t)$ and $\beta\,(0 \le \beta < 1)$ are the instantaneous received beacon signal power at timeslot t and the forgetting factor of the filter, respectively. The averaging interval of the first order filtering is given as $1/(1-\beta)$ timeslots. If the forgetting factor β is set to a large value, the older inputs are relatively forgotten slowly, and otherwise.

The available channels are listed in channel priority table as $\mathbf{P}_m = \{p_0, p_1, \cdots, p_{N_{ch}-1}\}$ with $\bar{I}_m^{(p_0)}(t) < \bar{I}_m^{(p_1)}(t) < \cdots < \bar{I}_m^{(p_{N_{ch}-1})}(t)$, where p_k and N_{ch} represent the channel index and the number of channels respectively. After the updating of channel priority table, the value of channel priority table will be sent to CC. Each AP 1-4) assigns channel(s) for connected STA(s) based on the order of CC and 1-5) broadcasts beacon signal on the assigned channel(s). If there is no channel being assigned at an AP, the AP broadcasts beacon signal on the highest-priority channel.

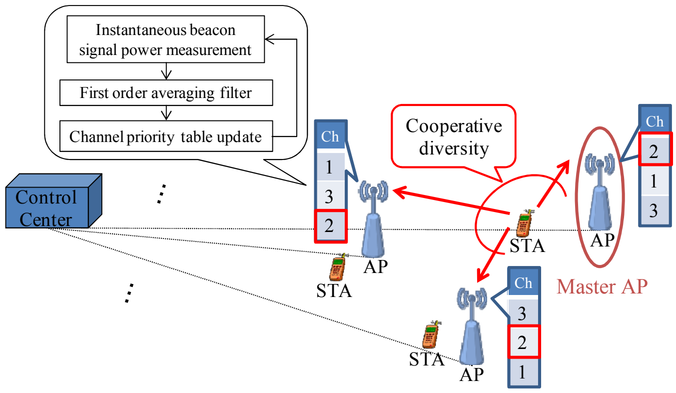


Figure 1. Network Model

2.2. Selection of cooperative AP candidates

As shown in Fig. 2 (b), Every STA 2-1) selects a group candidate of predetermined N_t APs based on received beacon power. The u-th STA's AP group candidate is expressed as $\mathbf{n}_u = \{n_{u,0}, n_{u,1}, \cdots, n_{u,N_t-1}\}$, where $n_{u,k}$ expresses AP index and $P_{u,n_{u,N_t-1}}(t) < \cdots < P_{u,n_{u,1}}(t) < P_{u,n_{u,0}}(t)$ with $P_{u,m}(t)$ is the beacon signal power received at u-th STA from m-th AP. If an STA does not have transmission request, the STA's algorithm 2-2) ends at the current timeslot, but if the STA has transmission request, the STA 2-3) sends transmission request with information about its own STA index and its AP group candidate, and 2-4) waits for response from CC. If 2-5) the STA receives NACK information from CC, the STA's transmission request 2-6) is blocked at the current timeslot. If 2-7) the STA receives ACK information form CC, the STA 2-8) starts the data transmission at the current timeslot with the selected AP(s) and the assigned channel in AP group.

2.3. Channel assignment and cooperative AP group decision on CC

The CC 3-1) receives STA's transmission request information and APs' channel priority tables. As all request information from STAs is collected, CC recognizes the set of requesting STAs' indexes as $\mathbf{u}_{\text{req}} = \{u_0, u_1, \cdots, u_{U_{\text{req}}-1}\}$ where u_k and U_{req} represent STA index and the total number of requesting STAs, respectively. The CC 3-2) sorts the requesting STAs' set in ascending order of the maximum received beacon signal power from AP on their group candidates. The sorted requesting STAs' indexes are expressed as a set of $\mathbf{u}'_{\text{req}} = \{u'_0, u'_1, \cdots, u'_{U_{\text{req}}-1}\}$ with $\mathbf{u}'_{\text{req}} \subseteq \mathbf{u}_{\text{req}}$ and $P_{u'_0,n_{u'_0},0}(t) < P_{u'_1,n_{u'_1},0}(t) < \cdots < P_{u'_{U_{\text{req}}-1},n_{u'_{U_{\text{req}}-1}},0}(t)$ with $P_{u'_k,n_{u'_k},0}(t)$ being the u'_k-th STA's maximum received beacon signal power from an AP on its AP group candidate, respectively. The 3-3)~3-11) operations are carried out in the order of the sorted STA indexes $u'_0, u'_1, \cdots, u'_{U_{\mathrm{req}}-1}$. The CC 3-3) checks the vacant channel of u'_k-th STA's AP group candidate $\mathbf{n}_{u'_k} = \{n_{u'_k,0}, n_{u'_k,1}, \cdots, n_{u'_k,N_t-1}\}$ from the highest-priority channel to the lowest-priority channel.

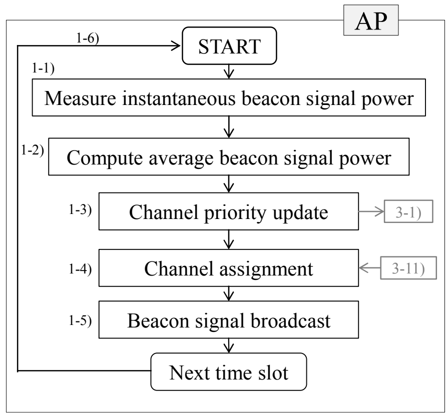
When vacant channel is not available in all APs in group candidate, 3-4) u'_k-th STA's transmission request is blocked and 3-5) CC sends NACK information to u'_k-th STA. When 3-6) vacant channel exists on $n_{u'_k,l}$-th AP, 3-7) the AP is set as master AP of u'_k-th STA's group. CC 3-8) selects master's vacant highest priority channel for the rest APs in the group candidate. After the channel selection on AP candidates, CC 3-9) checks whether the selected channel overlaps (i.e., the channel has already been selected for another STA) and 3-10) removes AP(s) with the channel overlap from the AP group candidate. Finally, 3-11) CC sends ACK information which contains AP(s) index(es) and channel to be used in the decided group.

As can be seen from flow 3-4) in Fig. 2(c), there can be STA whose transmission request is blocked. In section 3, we will evaluate the blocking probability.

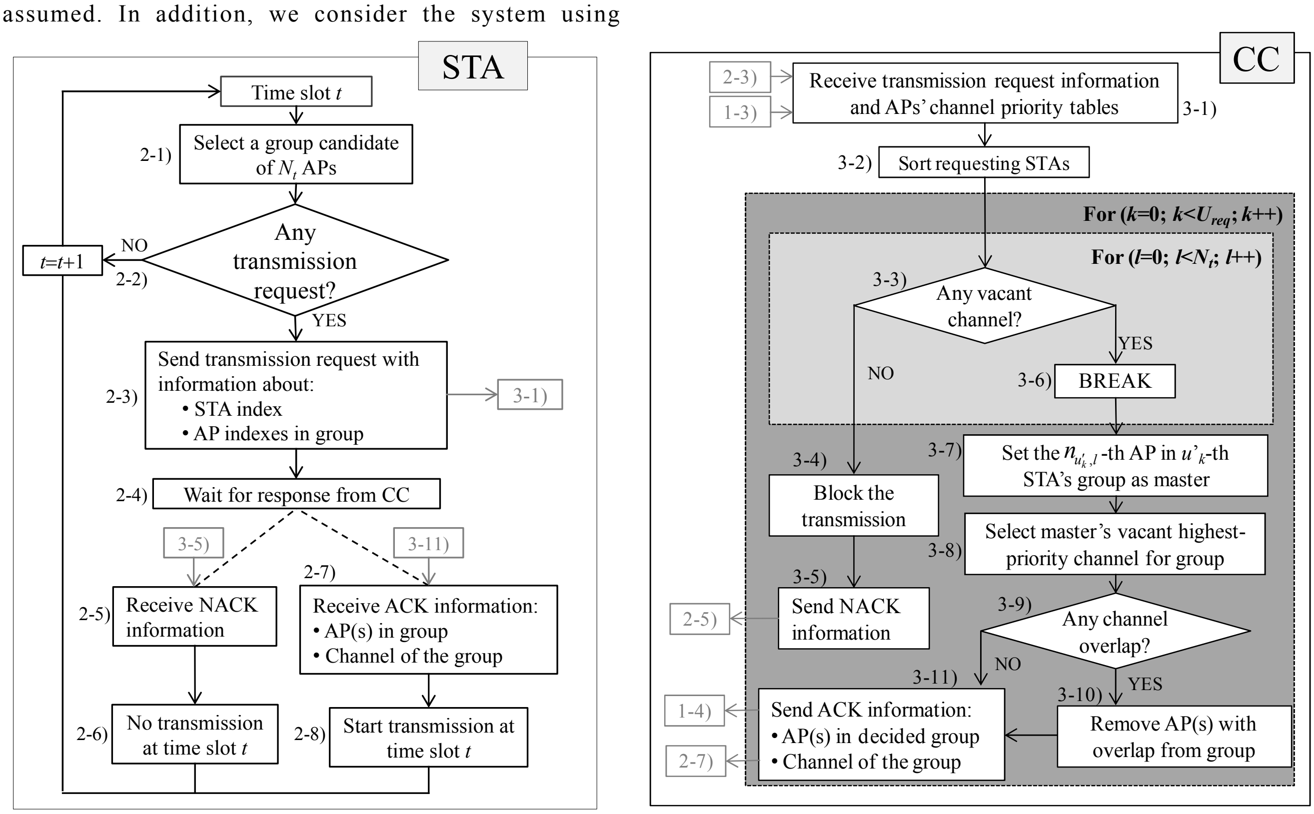
3. Computer Simulation

Computer simulation was carried out to evaluate the performance of the proposed AP grouping method combined with IACS-DCA. Table 1 summarizes the simulation conditions. The interference-limited condition is assumed. In addition, we consider the system using orthogonal frequency division multiplexing (OFDM) [5] transmission.

There are 200 initializations and each simulation run passes through 2000 timeslots. During the timeslots in each simulation run, all the STAs are assumed to be stationary (i.e., the fading and shadowing does not change). The results in this simulation are based on the measurement on timeslots t=1001~2000. AP measures the instantaneous received beacon signal power and updates the channel priority table at every timeslot. Also, at every timeslot, CC decides the AP grouping and selects channel to be assigned on every AP group. We assume a synchronous system in which all STAs and APs transmit their packets at the same time.



(a) AP

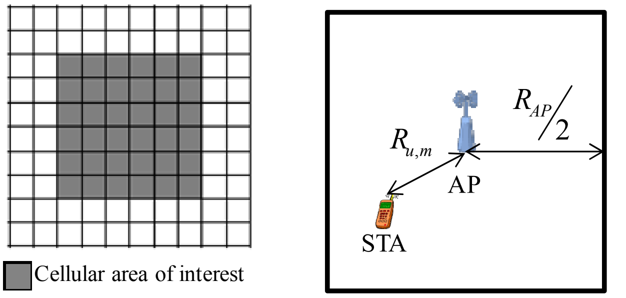


(b) STA (c) CC

Figure 2. Flowchart of the proposed AP grouping algorithm.

Table 1. Computer simulation conditions.

System	No. of channels	N_{ch}=4
	No. of subcarriers per channel	N_c=64
	Normalized transmit SNR	∞ (interference limited)
	No. AP candidates per STA	N_t=1, 2, 3
Channel	Fading type	Frequency-selective block Rayleigh
	Power delay profile	Sampling interval-spaced L=16-path uniform
	Path loss exponent	α=3.5
	Shadowing loss standard deviation	σ=5dB
IACS-DCA	Forgetting factor of first order filtering	β=0.99



(a) Cellular model (b) Geometry of AP and STA

Figure 3. Network model for computer simulation.

3.1. Network model

The network model considered in this paper is illustrated in Fig. 3. 100 rectangular cellular areas are considered and 36 areas in the middle (highlighted in Fig. 3(a)) are areas of interest in which the performance measurements are carried out. As shown in Fig. 3(b), an AP equipped with a single antenna is located at the center of each cellular area and the distance between adjacent APs is denoted by R_{AP}. One stationary STA is assumed to be located randomly in each cellular area with transmission probability p=1 at each timeslot.

3.2. Propagation channel model

In this paper, we assume a frequency-selective block Rayleigh fading channel which is composed of L distinct paths. The channel impulse response between m-th AP and u-th STA is given by

$$h_{u,m}(\tau)=\sum_{l=0}^{L-1} h_{m,u,l}\delta(\tau-\tau_l), , \tag{2}$$

where $h_{m,u,l}$ and τ_l are the complex-valued path gain with $E[\sum_{l=0}^{L-1}|h_{m,u,l}|^2]=1$ ($E[.]$ represents the ensemble average operation) and time delay of the l-th path, respectively. The similar fading channel is also assumed for the beacon signal transmission.

3.3. Signal representation

We consider uplink transmission in this paper. At the transmitter (STA), the binary information sequence is data-modulated and then, the data-modulated symbol sequence is divided into a sequence of blocks of N_c symbols each. Then, N_c-point inverse discrete Fourier transform (IDFT) is applied to form the OFDM signal block. The last N_g samples in each block are copied and inserted as a cyclic prefix (CP) into the beginning of the signal block before transmission. The length of the CP is assumed to be longer than the maximum path delay.

The transmitted OFDM signal block passes through a frequency-selective fading channel. At the receiver (AP), after CP removal, the received signal block is decomposed by N_c-point DFT into the orthogonal subcarrier components. The frequency domain transmitted signal by u-th STA to its selected m-th AP at the k-th subcarrier is expressed as

$$R_{u,m}(k)=\sqrt{2p_t\cdot r_{u,m}^{-\alpha}\cdot 10^{-\frac{\eta_{u,m}}{10}}}\cdot H_{u,m}(k)\cdot d_u(k)+\sum_{u'=0,u'\neq u}^{N_{\text{user}}-1}\left(\delta_{u,u'}\cdot\sqrt{2p_t\cdot r_{u',m}^{-\alpha}\cdot 10^{-\frac{\eta_{u',m}}{10}}}\cdot H_{u',m}(k)\cdot d_{u'}(k)\right)+N_m(k), \tag{3}$$

where $p_t=P_t\cdot R_{AP}^{-\alpha}$, $r_{u,m}=R_{u,m}/R_{AP}$, α, and $\eta_{u,m}$ denote the normalized STA's transmit power (with P_t is the STA's transmit power), the normalized distance between u-th STA and m-th AP, the path loss exponent, and the shadowing loss in dB having zero-mean and standard deviation σ, respectively. $H_{u,m}(k)$, $d_u(k)$, and $N_m(k)$ denote the frequency-domain channel gain at the k-th subcarrier between u-th STA and m-th AP, the transmitted signal from u-th STA and noise, respectively. $\delta_{u,u'}$=1 if the u-th STA's selected channel equals to u'-th STA's selected channel, and $\delta_{u,u'}$=0 otherwise.

At the receiver (AP), maximum-ratio combining (MRC) weight [6], which maximizes signal-to-interference power ratio (SIR) between u-th STA and m-th AP at the k-th subcarrier, is assumed to be used. The MRC weight at the k-th subcarrier can be expressed as

$$W_{u,m}(k)=\frac{\tilde{H}^*_{u,m}(k)}{\left|\sum_{u'=0,u'\neq u}^{N_{\text{user}}-1}\delta_{u,u'}\cdot\sqrt{2P_t}\tilde{H}_{u',m}(k)\right|^2}, \tag{4}$$

where $\tilde{H}_{u,m}(k)=\sqrt{r_{u,m}^{-\alpha}\cdot 10^{\frac{\eta_{u,m}}{10}}}\cdot H_{u,m}(k)$ and $(.)^*$ denotes the complex conjugate operation. The u-th STA's received signal after MRC at the k-th subcarrier can be expressed as

$$\tilde{R}_u(k)=\sum_{m=0}^{N_{AP}-1}\left(\delta'_{u,m}\cdot W_{u,m}(k)\cdot R_{u,m}(k)\right), \tag{5}$$

where $\delta'_{u,m}$=1 if m-th AP belongs to the u-th STA's selected AP(s). The SIR per block of u-th STA is calculated as

$$\mathrm{SIR}_u=\frac{\sum_{n=0}^{N_c-1}\left|\sum_{m=0}^{N_{AP}-1}\delta'_{u,m}\cdot W_{u,m}(k)\cdot\sqrt{2P_u}\cdot\tilde{H}_{u,m}(k)\right|^2}{\frac{1}{2}\sum_{n=0}^{N_c-1}\left|\sum_{m=0}^{N_{AP}-1}\delta'_{u,m}\cdot W_{u,m}(k)\left\{\sum_{u'=0,u'\neq u}^{N_{\mathrm{user}}-1}\left(\delta_{u,u'}\sqrt{2P_{u'}}\cdot\tilde{H}_{u',m}(k)\right)\right\}\right|^2},\quad(6)$$

3.4. Blocking Probability

Blocking probability caused by the application of proposed AP grouping is shown in Fig. 4. From the result, it is known that the blocking probability increases along with the increasing number of AP candidates N_t, due to the increasing probability of channel overlap. However, with total of 4 channels and N_t=1~3, the number of blocking probability is almost zero.

3.5. Diversity Order

The probability distribution of the diversity order after the group decision is shown in Fig. 5. From Fig. 5, It can be seen that the probability of full-diversity case (i.e., the number of cooperative APs is equal to the number of AP candidates N_t) decreases as the N_t increases. This is because the probability of channel overlap increases and the algorithm removes more APs from AP group candidates. However, as seen in Fig. 5, the probability of no-diversity case is relatively small for N_t>1, which means that almost all STAs can obtain the diversity effect by the proposed algorithm.

3.6. SIR Performance

SIR performance of the proposed AP grouping algorithm is shown in Fig. 6. It can be seen from Fig. 6 that the SIR performance significantly improves by using the proposed AP grouping algorithm. For example, the AP grouping with N_t=2 can improve the SIR at CDF=10^{-2} by about 6.5dB, compared to the conventional IACS-DCA without diversity.

In Fig. 6, it can also be seen that there is only a small amount of SIR improvement when the number of N_t increases from 2 to 3. This is because APs located far from the STA will be selected due to the increasing number of AP candidates N_t, and the contribution of these APs is relatively small.

4. Conclusion

In this paper, we proposed an AP grouping algorithm for AP cooperative diversity in a wireless network using IACS-DCA. By using the proposed AP grouping algorithm, each STA utilizes a predetermined number of APs for AP cooperative diversity. The number of APs to be involved in cooperative diversity is an important design parameter. We showed by computer simulation, that AP cooperative diversity using proposed AP grouping algorithm can improve the SIR at CDF=10^{-2} by about 6.5dB for 2-AP-candidate case with a total of 4 channels compared to the conventional IACS-DCA without diversity, while achieving low blocking probability.

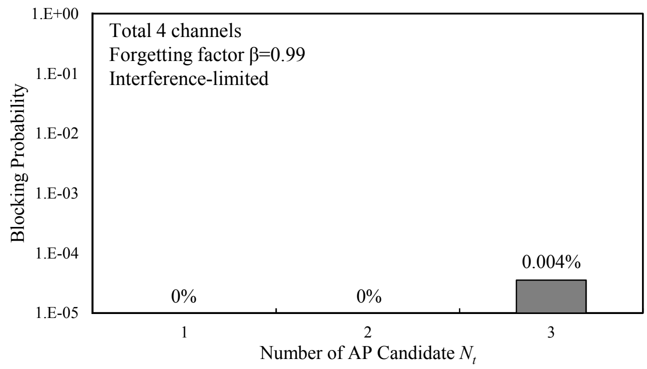


Figure 4. Blocking probability.

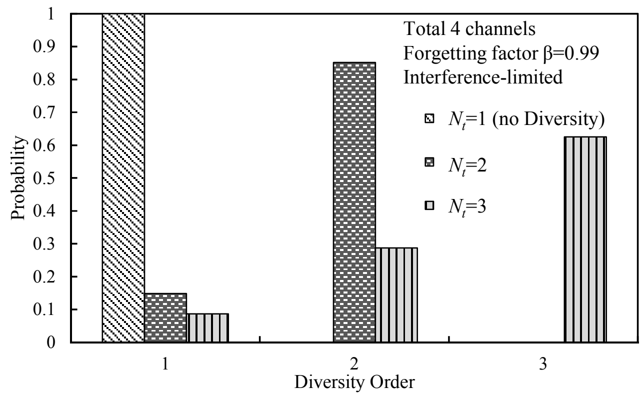


Figure 5. Diversity order.

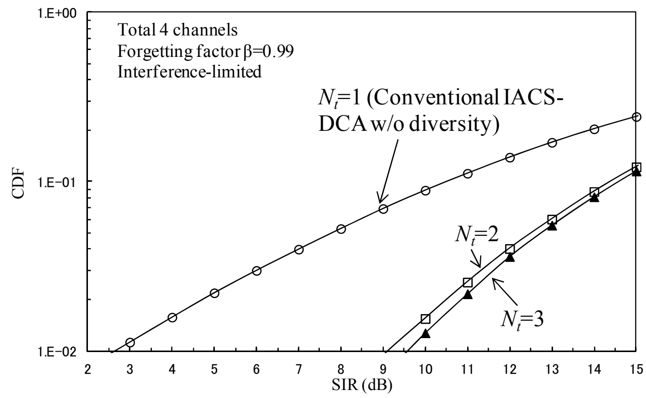


Figure 6. SIR performance.

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