AP Cooperative Diversity in Wireless Network Using Interference-Aware Channel Segregation Based Dynamic Channel Assignment

Martin T.H. Sirait[1] Yuki Matsumura[1] Katsuhiro Temma[1] Koichi Ishihara[2]
B. A. Hirantha Sithira Abeysekera[2] Tomoaki Kumagai[2] and Fumiyuki Adachi[3]
[1, 3]Dept. of Communications Engineering, Graduate School of Engineering, Tohoku University
6-6-05, Aza-Aoba, Aramaki, Aoba-ku, Sendai, Miyagi, 980-8579, Japan
[2]NTT Network Innovation Laboratories, NTT Corporation
1-1, Hikarinooka, Yokosuka-shi, 239-0847, Japan
[1]{martin, matsumura, tenma}@mobile.ecei.tohoku.ac.jp, [3]adachi@ecei.tohoku.ac.jp
[2]{ishihara.koichi, hirantha.abeysekera, kumagai.tomoaki}@lab.ntt.co.jp

Abstract—**Recently, we proposed interference-aware channel segregation based dynamic channel assignment (IACS-DCA) which forms a channel reuse pattern with low co-channel interference (CCI) in a distributed manner. The transmission performance of a wireless station (STA) located far from access points (APs) degrades due to path loss and shadowing loss. AP cooperative diversity is a well-known technique to improve the transmission performance. Since IACS-DCA operates so as to assign different channels to different APs located nearby each other, it is not an easy task to introduce AP cooperative diversity to a wireless network using IACS-DCA. In this paper, we propose an AP grouping and channel selection method for AP cooperative diversity in a wireless network using IACS-DCA. By computer simulation, we show that the proposed AP cooperative diversity can improve the transmission performance.**

Keywords—AP cooperative diversity; AP grouping; channel segregation; dynamic channel assignment; co-channel interference

I. INTRODUCTION

The number of channels available for wireless networks, e.g., IEEE 802.11-based wireless LANs, is limited, and therefore, the same channel needs to be reused by spatially separated access points (APs) or base stations (BSs). Note that the terminology AP is used in this paper. Since the co-channel interference (CCI) limits the transmission performance of wireless network, the channels must be reused while minimizing the CCIs received at all APs [1]. In order to mitigate the sophisticated channel assignment problem, we recently proposed interference-aware channel segregation based dynamic channel assignment (IACS-DCA) [2, 3]. In IACS-DCA, each AP periodically measures the CCIs on all available channels, computes the average CCI powers using the past CCI measurement results, updates its own channel priority table, and selects the channel with the lowest average CCI power (i.e., highest-priority channel). It was shown in [3] that IACS-DCA can form a channel reuse pattern with low CCI in a distributed manner.

The transmission performance of a wireless station (STA) located far from APs degrades due to path loss and shadowing loss [1]. AP cooperative diversity which utilizes a group of multiple APs to support an STA was studied [4, 5] to improve the transmission performance. The cooperating APs in a group need to use the same channel. However, IACS-DCA operates so that different channels are assigned to different APs located nearby each other. Therefore, the introduction of the AP cooperative diversity to a wireless network using IACS-DCA is not an easy task.

In this paper, we propose an AP grouping and channel selection method for AP cooperative diversity in a wireless network using IACS-DCA. We assume a network where several APs can communicate with an STA and all APs on the network are assumed to be connected to a control center (CC) which decides AP grouping and channel selection. All APs update their own channel priority table based on their CCI measurement results and inform the channel priority table to CC. 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. In the proposed method, the worst case for an STA occurs when all channels of APs in its group have been assigned, i.e., the transmission is blocked. Therefore, the transmission performance is improved at the cost of blocking probability.

The rest of the paper is organized as follows. Details of the proposed AP grouping and channel selection algorithm along with IACS-DCA are presented in Section II. In Section III, we examine the blocking probability, diversity order, and signal-to-interference power ratio (SIR) of the proposed algorithm by computer simulation. Section IV offers some concluding remarks.

II. AP GROUPING AND CHANNEL SELECTION METHOD FOR AP COOPERATIVE DIVERSITY

Using the proposed AP grouping and channel selection method, each AP periodically updates its channel priority table based on the CCI power measurement, and CC performs the AP grouping and channel selection based on channel priority table of each AP. Figs. 1(a), (b), and (c) show the flowcharts of proposed AP grouping and channel selection algorithm at AP, STA, and CC, respectively. The details of each algorithm are explained in the following.

A. Channel Priority Table Update on AP

In this paper, we assume that each AP is designed to transmit the beacon signal periodically for the measurement of instantaneous CCI power. As shown in Fig. 1(a), each AP periodically measures the total instantaneous received beacon signal power from other APs, computes the average beacon signal power based on the past beacon signal power measurement results, and updates the channel priority table.

The average received beacon signal power of each available channel is computed using the first order filtering [6]. The average beacon signal power $\bar{I}_m^{(c)}(t)$ received at the m-th AP on the c-th channel at timeslot t is given as

$$\bar{I}_m^{(c)}(t) = (1-\beta)\cdot I_m^{(c)}(t) + \beta\cdot \bar{I}_m^{(c)}(t-1), \tag{1}$$

where $I_m^{(c)}(t)$ and $\beta\,(0 \le \beta < 1)$ are the instantaneous received beacon signal power at timeslot t and the filter forgetting factor, respectively. 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 total number of available channels, respectively. After updating the channel priority table, AP sends information of channel priority table value to CC. Each AP receives information of connected STA(s) and assigned channel(s) from CC, and broadcasts beacon signal on the assigned channel(s). AP without assigned channel broadcasts beacon signal on its highest-priority channel.

B. *Selection of Cooperative AP Candidates*

As shown in Fig. 1(b), Every STA measures power of beacon signal transmitted by each AP, and selects a group candidate of predetermined N_t APs with the largest received beacon signal powers. 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 ID and $P_{u,n_{u,N_t-1}}(t) < \cdots < P_{u,n_{u,1}}(t) < P_{u,n_{u,0}}(t)$ with $P_{u,m}(t)$ as 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 ends at the current timeslot, but if the STA has transmission request, the STA sends transmission request with information about its own STA ID and its AP group candidate, and waits for response from CC. If the STA receives NACK information from CC, the STA's transmission request is blocked at the current timeslot. Otherwise, if the STA receives ACK information from CC, the STA obtains information of selected channel and connected AP(s) and starts data transmission on the channel assigned to its AP group.

C. *Decision of AP Group and Channel Assignment on CC*

CC receives information sent by AP, obtains value of the AP's channel priority table, and repeats the same process until information from all APs is obtained. CC receives STA's transmission request through APs, and obtains requesting STA's ID, information of its AP candidates and its highest received beacon signal power. As all request information from STAs is collected, CC recognizes the set of requesting STAs' IDs as $\mathbf{u}_{\text{req}} = \{u_0, u_1, \cdots, u_{U_{\text{req}}-1}\}$, where u_k and U_{req} represent STA ID and the total number of requesting STAs, respectively. CC then sorts the requesting STAs' set in ascending order of each STA's highest received beacon signal power from AP on their group candidates. The sorted requesting STAs' IDs 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 $P_{u'_k,n_{u'_k,0}}(t)$ as the u'_k-th STA's maximum received beacon signal power from an AP on its AP group candidate, respectively.

The following operations are carried out in the order of the sorted STA indexes $u'_0, u'_1, \cdots, u'_{U_{\text{req}}-1}$. CC checks the vacant channel of each AP on u'_k-th STA's AP group candidate in the order of $n_{u'_k,0}, n_{u'_k,1}, \cdots, n_{u'_k,N_t-1}$, from its highest-priority channel to the lowest-priority channel. When vacant channel is not available in all APs in group candidate, CC sends NACK information to u'_k-th STA to inform that the transmission request is blocked. When vacant channel exists on $n_{u'_k,l}$-th AP, the AP is set as master AP of u'_k-th STA's group. CC selects master AP's vacant highest priority channel for the rest of APs in the group candidate. After the channel selection on AP candidates $\mathbf{n}_{u'_k} = \{n_{u'_k,0}, n_{u'_k,1}, \cdots, n_{u'_k,N_t-1}\}$, CC checks whether the selected channel overlaps (i.e., the channel is not vacant or has already been selected for another STA) on every AP candidate. If the selected channel is vacant on $n_{u'_k,l}$-th AP, the selected channel is assigned to the AP and the AP is set as the connected AP for u'_k-th STA. Otherwise, the AP is removed from u'_k-th STA's group. Finally, CC sends ACK information notifying the selected channel and connected AP ID(s) to u'_k-th STA, and notifies connected STA IDs and assigned channels to all APs.

As the number of AP candidates N_t increases, the number of channels simultaneously assigned on AP also increases. Therefore, the probability that there is no vacant channels on all AP candidates of an STA also increases, and as can be seen from flows 3-9)~3-12) in Fig. 1(c), the probability of STA's transmission request being blocked (i.e., blocking probability) exists. Moreover, from flows 3-15)~3-18) in Fig. 1(c), we can also see that in the proposed algorithm, CC allocates only vacant channels on APs to STAs to prevent a channel being used by several STAs on an AP (i.e., channel overlap), in order to mitigate CCI caused by channel overlap. Thus, the number of APs connected to every STA is not always the same as the number of AP candidates. By the characteristics mentioned above, in Section III, we will discuss about the blocking probability, number of APs connected to each STA (i.e., diversity order), and the effect of the channel overlap prevention of this algorithm.

III. COMPUTER SIMULATION

Computer simulation was carried out to evaluate the performance of the proposed AP grouping and channel selection method for a wireless network using IACS-DCA and orthogonal frequency division multiplexing (OFDM) [7]. Table I summarizes the simulation conditions. The same transmit power is assumed for all transmitters. Furthermore, the interference-limited condition is assumed.

A. *Network Model*

The network model considered in this paper is illustrated in Fig. 2. An area of 100 rectangular cells is considered, and an area of interest for performance measurement consists of 36 cells (highlighted in Fig. 2(a)). As shown in Fig. 2(b), an AP equipped with a single antenna is located at the center of each cell and the distance between adjacent APs is denoted by R_{AP}.

One stationary STA is assumed to be located randomly in each cell with transmission request probability p=1 at each timeslot.

B. Propagation Channel Model

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

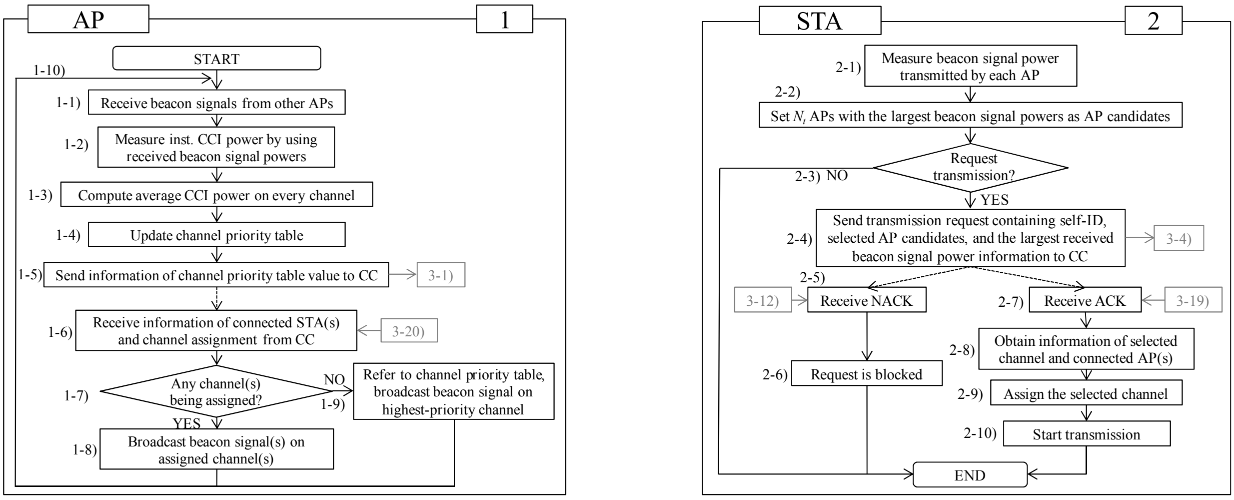
$$h_{u,m}(\tau) = \sum_{l=0}^{L-1} h_{u,m,l}\,\delta(\tau - \tau_l)\,, \tag{2}$$

where $h_{u,m,l}$ 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.

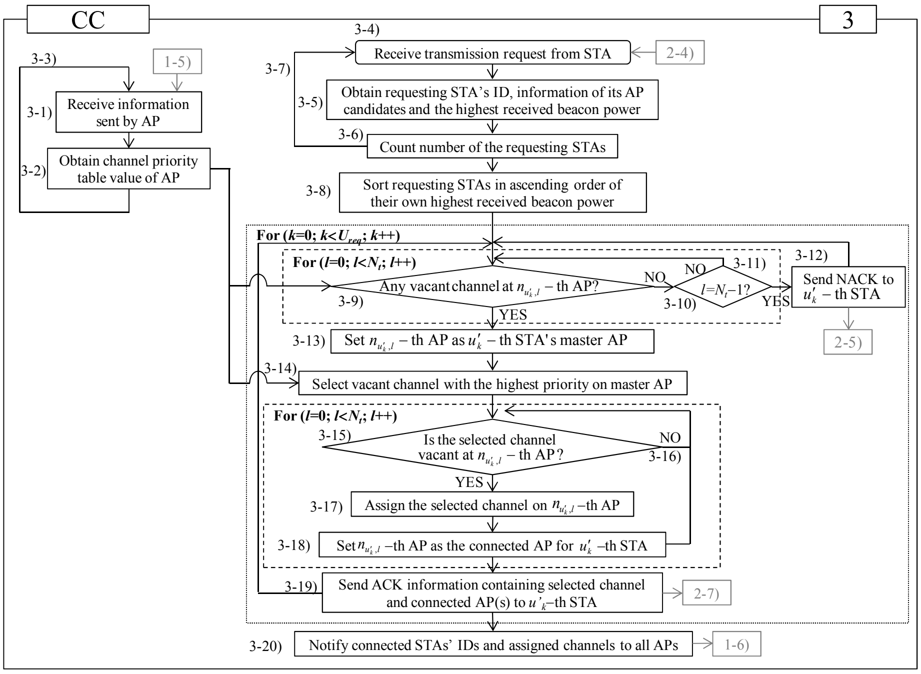
C. Signal Transmission

We consider the 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 CP length 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 signal at the k-th subcarrier which is transmitted from the u-th STA and received by the m-th AP is expressed as



(a) AP (b) STA

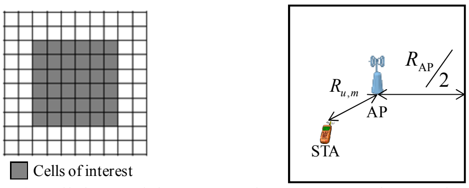


(c) CC

Fig. 1. Flowcharts of the proposed AP grouping and channel selection algorithm.

TABLE I. COMPUTER SIMULATION CONDITIONS.

System	No. of channels	N_{ch}=4
	Transmission	OFDM with N_c=64 subcarriers
	Normalized transmit SNR	∞ (interference limited)
	No. AP candidates per STA	N_t=1, 2, 3
Channel	Fading type	Static frequency-selective 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 filter	β=0.99



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

Fig. 2. Network model for computer simulation.

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

where $p_t=P_t\cdot R_{AP}^{-\alpha}$, $r_{u,m}=R_{u,m}/R_{\mathrm{AP}}$, α, and $\eta_{u,m}$ denote the normalized STA's transmit power (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_{STA} denote the frequency-domain channel gain at the k-th subcarrier between u-th STA and m-th AP, the transmitted signal from the u-th STA, and a total number of STAs, respectively. $\delta_{u,u'}$=1 if u-th STA's selected channel equals to u'-th STA's selected channel, and $\delta_{u,u'}$=0 otherwise.

The beacon signal power received at m-th AP on the c-th channel at timeslot t, used in Eq. (1), is expressed as

$$I_m^{(c)}(t)=\sum_{k=0}^{N_c-1}\left\{\sum_{n=0,n\neq m}^{N_{AP}-1}\delta_n^{(c)}\sqrt{2p_t'\cdot r_{m,n}^{-\alpha}\cdot 10^{-\frac{\eta_{m,n}}{10}}}\cdot\left|H_{m,n}(k)\right|\right\}^2, \tag{4}$$

where $p_t'=P_t'\cdot R_{AP}^{-\alpha}$, $r_{m,n}=R_{m,n}/R_{\mathrm{AP}}$, $\eta_{m,n}$ and N_{AP} denote the normalized AP's transmit beacon signal power (with P_t' is the AP's transmit beacon signal power), the normalized distance between m-th AP and n-th AP, the shadowing loss in dB, and a total number of APs, respectively. $\delta_n^{(c)}=1$ if the n-th AP assigns c-th channel at timeslot t, and $\delta_n^{(c)}=0$ otherwise. The transmitted beacon signal is assumed to be known and can be detected perfectly.

At the receiver (CC), maximum-ratio combining (MRC) weight [8], which maximizes 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

$$W_{u,m}(k)=\frac{\widetilde{H}^*{}_{u,m}(k)}{\left|\sum_{u'=0,u'\neq u}^{N_{\mathrm{STA}}-1}\delta_{u,u'}\cdot\sqrt{2p_t}\widetilde{H}_{u',m}(k)\right|^2}, \tag{5}$$

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

$$\widetilde{R}_u(k)=\sum_{m=0}^{N_{AP}-1}\left(\delta'_{u,m}\cdot W_{u,m}(k)\cdot R_{u,m}(k)\right), \tag{6}$$

where $\delta'_{u,m}=1$ if m-th AP belongs to the u-th STA's connected AP(s), and $\delta'_{u,m}=0$ otherwise. SIR per block of u-th STA is calculated as [3]

$$\mathrm{SIR}_u=\frac{\sum_{k=0}^{N_c-1}\left|\sum_{m=0}^{N_{AP}-1}\delta'_{u,m}\cdot W_{u,m}(k)\cdot\sqrt{2p_t}\cdot\widetilde{H}_{u,m}(k)\right|^2}{\frac{1}{2}\sum_{k=0}^{N_c-1}\left|\sum_{m=0}^{N_{AP}-1}\delta'_{u,m}\cdot W_{u,m}(k)\left\{\sum_{u'=0,u'\neq u}^{N_{\mathrm{STA}}-1}\left(\delta_{u,u'}\sqrt{2p_t}\cdot\widetilde{H}_{u',m}(k)\right)\right\}\right|^2}. \tag{7}$$

D. Diversity Order and Blocking Probability

The probability distribution of the diversity order after the group decision is shown in Fig. 3. From the result, with total of 4 channels and N_t=1~3, the number of blocking probability caused by the application of the proposed AP grouping and channel selection is almost zero and it is verified that the blocking probability increases along with the increasing number of AP candidates N_t, because probability that there is no any vacant channel in AP candidate(s) increases. However, the blocking probability when number of AP candidate N_t=1 of the proposed algorithm exists even 1 STA is distributed on each cell, because an AP might be selected as the only AP candidate by several STAs due to the AP selection based on the instantaneous beacon power received by STA (i.e., when the number of STAs selecting the same AP candidate is larger than N_{ch}=4, the blocking occurs).

Moreover, it can be seen that the probability of full-diversity case (i.e., the number of cooperative APs connected to STA 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 hence the algorithm removes more APs from AP group candidates. However, as seen in Fig. 3, 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.

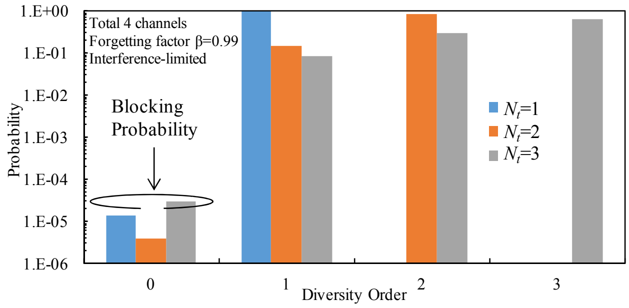


Fig. 3. Diversity order of proposed AP grouping.

E. SIR Performance

SIR performance of the proposed AP grouping algorithm is evaluated and shown in Fig. 4. It can be seen that even for the case of single AP candidate, i.e., N_t=1 (without AP cooperative diversity), AP selection based on instantaneous beacon power can improve the SIR performance compared to the AP selection based on path loss (i.e., distance). The SIR performance improves more with AP cooperative diversity

(N_t>1) due to the effect of antenna diversity and channel overlap prevention. For example, the AP grouping with N_t=2 and 3 can improve the SIR at CDF=10^{-2} by about 1.8dB and 2.2dB, respectively, compared to no-diversity case (N_t=1). In Fig. 4, 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 (0.4dB SIR improvement at CDF=10^{-2}). This is because APs located far from the STA will be selected as the number of AP candidates N_t increases, and the contribution of these APs is relatively small. The effect of channel overlap prevention is discussed in more detail below.

To evaluate the effect of channel overlap prevention of the proposed algorithm, we compare the proposed grouping method with 2 other grouping methods without channel overlap prevention. The first grouping method (this is called type-1 grouping) is the grouping which neglects the channel overlaps occurred on all APs (i.e., the selected master AP and other AP candidates) of each STA. In other words, in type-1 grouping, the highest-priority channel of master AP is selected for AP cooperative group, regardless of whether the selected channel is vacant or not. Therefore, STA's diversity order is always N_t on the type-1 grouping. On the other hand, the second grouping method for comparison (this is called type-2 grouping) considers channel overlap prevention only at the selected master AP. In type-2 grouping, vacant channel with the highest-priority of master AP is selected for AP group candidate. But, after the channel selection on other AP candidates, the transmissions are carried out even if the selected channel has been already selected for other STA's AP group(s), i.e., the channel overlap occurs.

SIR comparison of the proposed grouping and the type-1 grouping is shown in Fig. 5. It can be seen that SIR performance degrades highly on type-1 grouping because of large CCI caused by the use of more overlapping channels. The degradation is significant when AP candidate N_t=1 because most of the overlapping channels occurred on master AP (i.e., AP with the best propagation condition).

SIR comparison of the proposed grouping and the type-2 grouping is shown in Fig. 6. It can be seen that type-2 grouping has a worse SIR performance compared to the proposed grouping when AP candidates N_t>1, because on AP candidates other than master APs, the transmission are carried out even with the channel overlaps. The SIR of the type-2 grouping is better compared to the type-1 grouping. This shows that channel overlap on master APs brings a significant SIR degradation.

IV. CONCLUSION

In this paper, we proposed an AP grouping and channel selection algorithm for AP cooperative diversity in a wireless network using IACS-DCA. By using the proposed algorithm, every STA utilizes a predetermined number of AP candidates for AP cooperative diversity with prevention of channel overlap. We showed by computer simulation that in a network system with 4 total channels, while achieving low blocking probability, AP cooperative diversity using our proposed algorithm can improve the uplink SIR at CDF=10^{-2} by about 1.8dB and 2.2dB for 2 and 3 AP-candidate case respectively, compared to the no-diversity case. Also, the proposed grouping method achieves a better uplink SIR compared to other grouping methods which do not consider the channel overlap prevention. More detailed evaluations such as network throughput and also a development of improved algorithm in order to minimize the blocking probability are important topics for future study.

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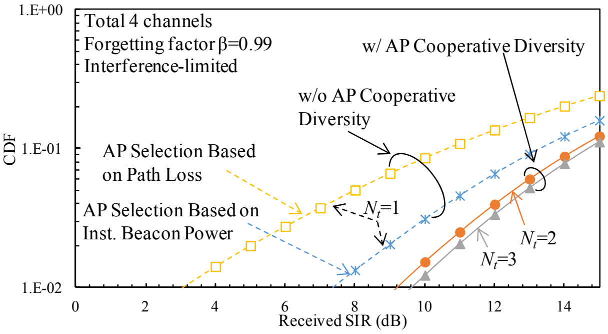

Fig. 4. SIR of proposed AP grouping.

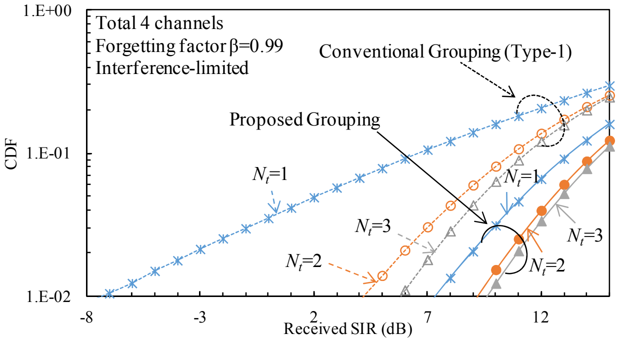

Fig. 5. SIR comparison of type-1 and proposed AP grouping.

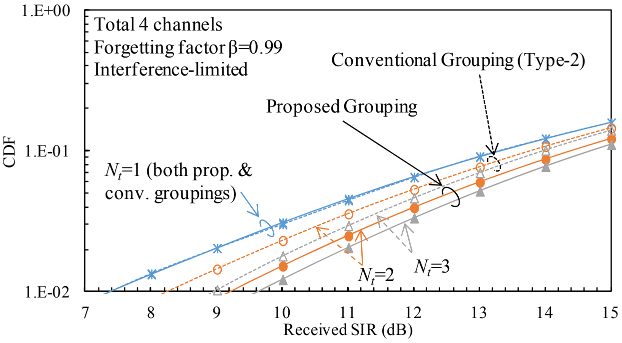

Fig. 6. SIR comparison of type-2 and proposed AP grouping