

# Multi-Channel Access in Wireless Networks Using Interference-Aware Channel Segregation Based Dynamic Channel Assignment

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**Abstract**—The co-channel interference (CCI) limits the capacity of wireless networks due to the limited number of available channels and the fact that the same channel must be reused in the system. Recently, we proposed the interference-aware channel segregation based dynamic channel assignment (IACS-DCA). Stable channel reuse pattern can be formed in a distributed manner which can minimize the CCI experienced at access points (APs) or base stations (BSs). In this paper, we introduce a multi-channel access technique for the IACS-DCA. Each AP has channel priority table, in which the channels are listed by the ascending order of average CCI power. Original IACS-DCA assumes the single channel access using the first priority channel with the lowest average CCI power. By using multiple channels at the same time in the descending priority order, more number of users can access an AP. However, the use of channels below the first orders at the same time increases the CCI and may make the channel reuse pattern unstable. We examine, by computer simulation, the channel reuse pattern and confirm that the IACS-DCA improves the signal-to-interference power ratio (SIR) even with multi-channel access compared to the conventional quasi-DCA using multi-channel access.

**Keywords**—channel segregation; dynamic channel assignment; co-channel interference; multi-channel access

## I. INTRODUCTION

The number of channels available for wireless network is limited. Hence, 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, it is necessary to minimize the total CCI which is caused by all APs or BSs in a network. In the popular wireless local area network (WLAN), when powered on, each AP measure the CCI power on the available channels and selects the best channel having the lowest CCI (in this paper, this is referred to as the quasi-DCA), then the AP continues to use the selected channel until it is powered off. However, the CCI environment may change and therefore, the selected channel may not be the best.

Dynamic channel assignment (DCA) [1]-[3] has been studied extensively in the literature [4]-[6]. One promising DCA is the channel segregation based DCA (CS-DCA) [7],[8]. Recently, we proposed an interference-aware CS-DCA (IACS-DCA) [9], in which each AP periodically monitors the CCI

environment and computes the average CCI powers (obtained from past CCI measurements) of all available channels. Each AP has the channel priority table, in which the channels are listed with the descending priority order (i.e., increasing order of CCI power). AP selects the channel having the lowest average CCI power. It was shown that IACS-DCA can form a stable channel reuse pattern in a distributed manner [10].

Recently, various wireless terminals have been spread rapidly in our daily life and a large number of users and devices use WLAN. It is required that the limited number of channels must be used more efficiently. In this paper, to remedy this problem, we study the IACS-DCA with multi-channel access which uses the channels below the first orders at the same time in AP. We show, by computer simulation, that even with multi-channel access, the IACS-DCA improves the signal-to-interference power ratio (SIR) compared to the conventional quasi-DCA.

The rest of the paper is organized as follows. Sect. II describes IACS-DCA and presents the multi-channel access operation in IACS-DCA. In Sect. III, we examine the stability of channel reuse pattern and the SIR distribution by computer simulation. Sect. IV offers some concluding remarks.

## II. MULTI-CHANNEL ACCESS IN IACS-DCA

In this paper, we consider time division duplex (TDD) using orthogonal frequency division multiplexing (OFDM) [11] transmission. TDD transmission timing is assumed to be synchronized for all the APs and STAs.

### A. IACS-DCA [10]

IACS-DCA flowchart is shown in Fig. 1. Using IACS-DCA, each AP is designed to periodically measure the uplink CCI power from STAs (i.e., the CCI power from STAs connected to other APs) and compute the moving average CCI power on each channel using the first order filtering [12]. Then, the channel priority table is updated in which the channels are listed in ascending order of the CCI power.

The number of available channels is denoted by  $N_{ch}$ . The moving average CCI power on the  $ch$ -th channel ( $ch=0\sim N_{ch}-1$ ) measured by the  $m$ -th AP (AP( $m$ )) at timeslot  $t$  is given by

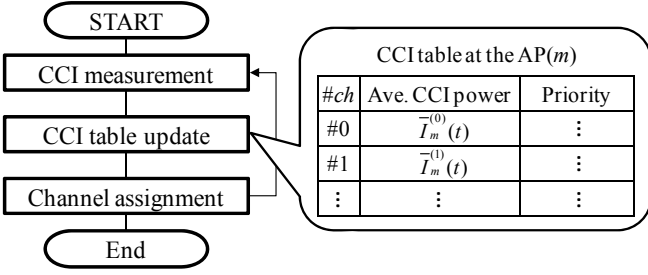


Fig. 1. Flowchart of IACS-DCA.

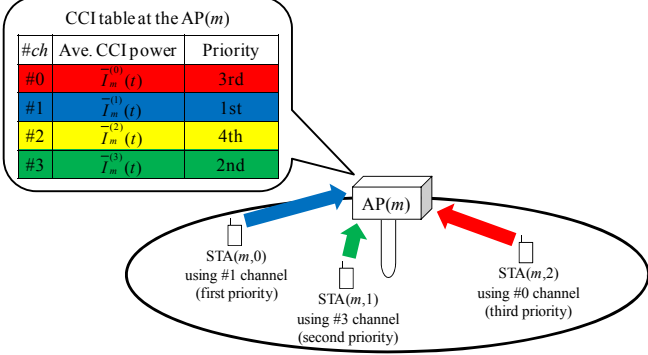


Fig. 2. Multi-channel access.

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

where  $\bar{I}_m^{(ch)}(t)$  and  $\beta$  denote instantaneous CCI power at timeslot  $t$  and filter forgetting factor, respectively. According to Eq. (1), the CCI table is updated at every timeslot. If the value of  $\beta$  is set too small, the average CCI power is strongly affected by the instantaneous CCI power. Hence,  $\beta \approx 1$  is required for constructing a stable channel reuse pattern [10].

### B. Multi-channel access based on channel priority

Fig. 2 illustrates the multi-channel access using the IACS-DCA. In the case of single-channel access, each AP selects only the first priority channel (i.e., the channel experiencing the lowest moving average CCI power) and communicates with STAs on the selected channel. Unlike the single-channel access case, the multi-channel access allows to use the channels below the first priority. STA( $m,u$ ) represents the STA communicating with AP( $m$ ) using the ( $u+1$ )-th priority channel. If AP uses more than one channel, the CCI power increases and the channel reuse pattern may become unstable.

## III. COMPUTER SIMULATION

We verify the stability of the channel reuse pattern on each priority channel and along with the SIR distribution by means of computer simulation.

Table I. shows the simulation conditions. The interference-limited condition is assumed. STAs are assumed to be stationary. AP measures the uplink instantaneous CCI power from STAs by communicating with other APs and then updates the CCI table at every timeslot. In this computer simulation, it is assumed that all STAs transmit uplink packets at every timeslots. The propagation channel is assumed to be

characterized by distance-dependent path loss with path loss exponent  $\alpha=3.5$  and  $L=16$ -path frequency-selective block Rayleigh fading; for simplicity, shadowing loss is not considered. The value of the filter forgetting factor  $\beta$  is set to 0.99 (an equivalent averaging interval of 100 time slots).

### A. Network model

The network model is illustrated in Fig. 3.  $A_{\text{all}}=100$  cells are considered and  $A_{\text{int}}=36$  cells (colored regions in Fig. 3(a)) are the cells of interest to examine the channel reuse pattern and the SIR distribution. As shown in Fig. 3(b), each AP equipped with a single antenna is located at the center of each cell and the distance between adjacent APs is denoted by  $R_{\text{AP}}$ .

Stationary  $U$  STAs ( $1 \leq U \leq N_{ch}$ ) are assumed to be uniformly located in each cell. The channel priority table is updated every timeslot.

For quantitative evaluation, we evaluate the autocorrelation function of channel reuse pattern [10] which is defined as

$$R(n) \equiv E \left[ \frac{1}{A_{\text{int}}} \sum_{\{m \in U_m\}} \sum_{ch=0}^{N_{ch}-1} q_{ch}(m,t) \cdot q_{ch}(m,t-n) \right], \quad (2)$$

where  $U_m \in \{22,23,\dots,77\}$  is the set of indices of the cells of interest shown in Fig. 3(a).  $q_{ch}(m,t)$  is the function that gives 1 when AP( $m$ ) uses  $ch$ -th channel on timeslot  $t$  and 0 for otherwise.  $E[\cdot]$  denotes the ensemble average operation. In fact, Eq. (2) compares the channel reuse pattern of timeslot  $t$  with that of timeslot  $t-n$  and the average number of APs which use the same channel is counted. As the channel distribution pattern satisfies a stable condition,  $R(n)$  approaches to 1.

### B. Propagation channel model and signal representation

We assume a stationary frequency-selective block Rayleigh fading channel. The  $k$ -th OFDM subcarrier of the  $ch$ -th channel received by AP( $m$ ) is represented as

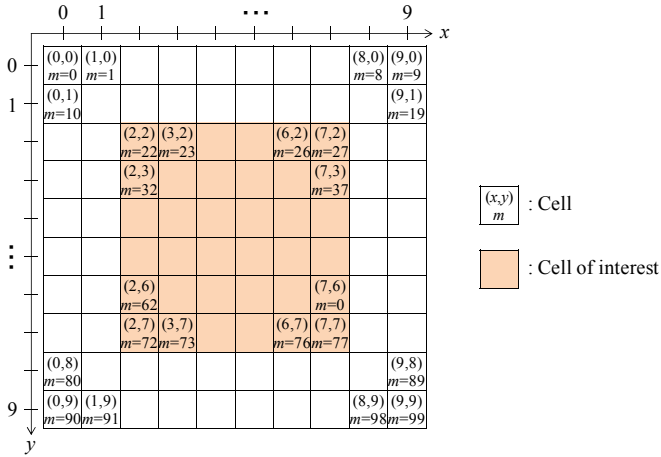
$$Y_m^{(ch)}(k) = q_{(m,u)}^{(ch)} \sqrt{2p_{(m,u)}^{(\text{Tx})} \cdot r_{m,(m,u)}^{-\alpha} \cdot 10^{\frac{\eta_{m,(m,u)}}{10}}} \cdot H_{m,(m,u)}^{(ch)}(k) \cdot d_{(m,u)}(k) + I_m^{(ch)}(k) + N_m^{(ch)}(k) \quad (3)$$

where  $p_{(m,u)}^{(\text{Tx})} = P_{(m,u)}^{(\text{Tx})} \cdot R_{\text{AP}}^{-\alpha}$  and  $r_{m,(m,u)} = R_{m,(m,u)}/R_{\text{AP}}$  are the normalized transmit power and the normalized AP( $m$ )-STA( $m,u$ ) distance, respectively. In Eq. (3),  $d_{(m,u)}(k)$  is the transmitted signal from STA( $m,u$ ) and  $H_{m,(m,u)}^{(ch)}(k)$  is the frequency-domain channel gain at  $k$ -th frequency of  $ch$ -th channel between AP( $m$ ) and STA( $m,u$ ).  $q_{(m,u)}^{(ch)}$  represents whether the STA( $m,u$ ) uses the  $ch$ -th channel or not, i.e.,  $q_{(m,u)}^{(ch)}$  equals to 1 when STA( $m,u$ ) uses the  $ch$ -th channel, otherwise  $q_{(m,u)}^{(ch)}$  equals to 0. It is observed that  $Y_m^{(ch)}(k)$  contains the CCI  $I_m^{(ch)}(k)$  and noise  $N_m^{(ch)}(k)$ , where  $I_m^{(ch)}(k)$  is the CCI from STAs connected to other APs of  $ch$ -th channel defined by

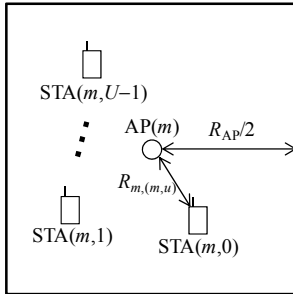
$$I_m^{(ch)}(k) = \sum_{m'=0}^{A_{\text{all}}-1} \sum_{u'=0}^{U-1} q_{(m',u')}^{(ch)} \cdot \sqrt{2p_{(m',u')}^{(\text{Tx})} \cdot r_{m,(m',u')}^{-\alpha} \cdot 10^{\frac{\eta_{m,(m',u')}}{10}}} \cdot H_{m,(m',u')}^{(ch)}(k) \cdot d_{(m',u')}^{(ch)}(k) \quad (4)$$

TABLE I. COMPUTER SIMULATION CONDITIONS

Network	No. of co-channel cells	$A_{cell}=100$
	No. of channels	$N_{ch}=4$
	No. of STAs per cell	$U=1-4$
	Normalized Transmit SNR	$\infty$ (interference limited)
Propagation channel	Fading type	Frequency-selective block Rayleigh
	Power delay profile	Symbol-spaced $L=16$ -path uniform power delay
	Path loss exponent	$\alpha=3.5$
	Shadowing loss standard deviation	$\sigma=0$ (dB)
IACS-DCA	CCI power measurement	Ideal
	Forgetting factor of first order filtering	$\beta=0.99$



(a) Cellular structure



(b) Geometry of AP and STAs

Fig. 3. Network model.

AP measures the instantaneous CCI power when its STA does not transmit the packet. The measured instantaneous CCI power of  $ch$ -th channel on AP( $m$ ) at timeslot  $t$  is given by

$$I_m^{(ch)}(t) = \frac{1}{N_c} \sum_{k=0}^{N_c-1} \left| J_m^{(ch)}(k) + N_m^{(ch)}(k) \right|^2, \quad (5)$$

where  $N_c$  is the number of OFDM subcarriers. The received SIR after coherent detection at the  $k$ -th subcarrier observed by AP( $m$ ) can be represented as

$$SIR_{(m,u)}(k) = \frac{2P_{(m,u)}^{(Tx)} \cdot r_{m,(m,u)}^{-\alpha} \cdot 10^{-\frac{\eta_{m,(m,u)}}{10}} |H_{m,(m,u)}^{(ch)}(k)|^2 |d_{(m,u)}(k)|^2}{\frac{1}{2} |J_m^{(ch)}(k)|^2}. \quad (6)$$

In this paper, the block-averaged SIR is used which is defined by

$$SIR_{(m,u)} = \frac{1}{N_c} \sum_{k=0}^{N_c-1} SIR_{(m,u)}(k). \quad (7)$$

### C. Channel reuse pattern

Fig. 4 shows one-shot observation of channel reuse pattern formed by the IACS-DCA on each priority. The initial channel reuse pattern at time  $t=0$  was generated randomly and STA location is set as Fig. 4(a). The conventional single-channel access ( $U=1$ ) uses the first priority channel only. Fig. 4(b) shows the channel reuse pattern of the first priority channel. On the other hand, the multi-channel access allows to use channels below the first priority. It can be seen from Figs. 4(b)-(e) that although a stable channel reuse pattern can be formed in case of single-channel access ( $U=1$ ), the channel reuse pattern seems to be unstable in case of multi-channel access ( $U=2-4$ ) even after enough CCI averaging (i.e.,  $t \gg 100$ ).

### D. Stability of the channel reuse pattern

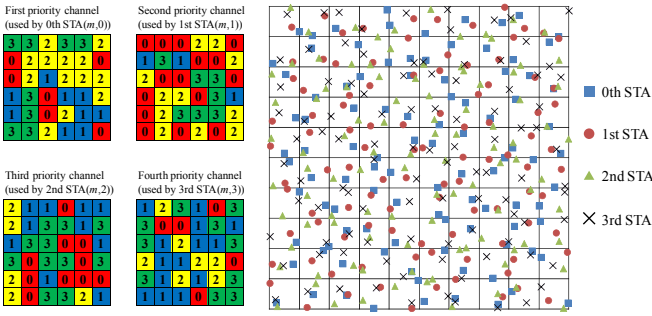
The stability of the channel reuse pattern can be quantitatively evaluated by the autocorrelation of channel reuse pattern [10]. Fig. 5 shows the autocorrelation of channel reuse pattern on the first to fourth each priority channels. The channel reuse pattern on timeslot  $t=2000$  is assumed to be the reference. We can see from Fig. 5 that the autocorrelation lower as  $U$  increases. This is a undesirable result, but the achievable uplink SIR can be improved compared to the conventional quasi-DCA using multi-channel access. This will be confirmed in the next subsection.

### E. SIR distribution

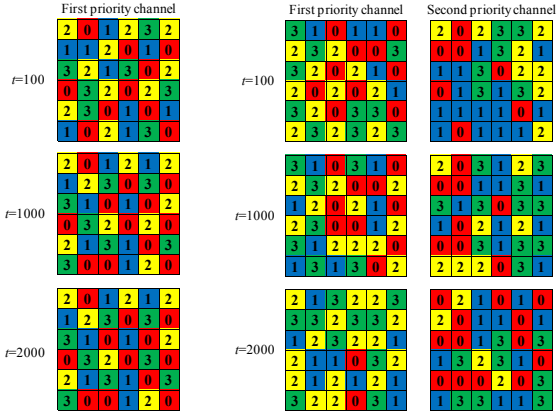
Fig. 6 plots the cumulative distribution function (CDF) of uplink SIR. The SIR is measured at timeslot  $t=1500 \sim 2000$  for achieving sufficient CCI average. For comparison, the CDF of uplink SIR with quasi-DCA with multi-channel access is also shown. The multi-channel access is realized in quasi-DCA as follows: every time each AP is powered on, it measures the CCI power of all available channels, and uses multiple channels in ascending order of CCI power. It can be seen from Fig. 6 that the IACS-DCA provides the improved SIR compared to quasi-DCA. The SIR level at  $\text{CDF}=10^{-2}$  is improved by about 4.1dB (1.5dB) for the first (second) priority channel when  $U=2$ . When  $U=3$ , the SIR level can be improved on all the priority channels. However, when  $U=4$  (i.e., all channels are used), the SIR level of the 4th channel slightly degrades compared to quasi-DCA.

## IV. CONCLUSIONS

In this paper, we introduced multi-channel access to the IACS-DCA. It was shown that although the channel reuse pattern becomes unstable when multi-channel access is used, IACS-DCA can improve the uplink SIR compared to the conventional quasi-DCA using multi-channel access.

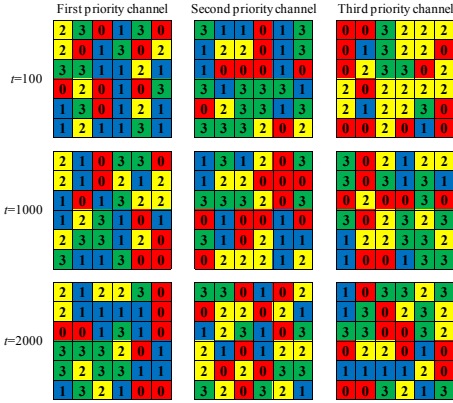


(a) Initial channel reuse pattern at time  $t=0$  and location of STAs

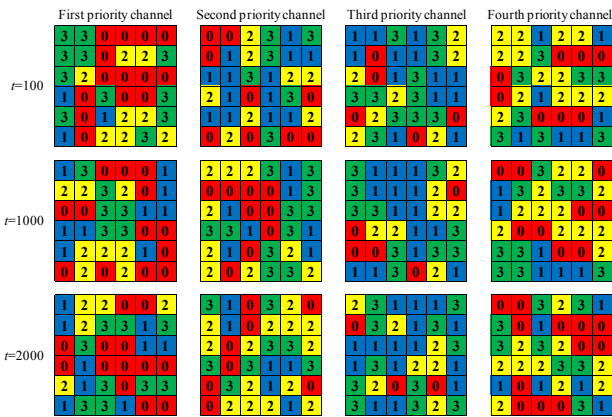


(b)  $U=1$

(c)  $U=2$



(d)  $U=3$



(e)  $U=4$

Fig. 4. An example of channel reuse pattern of each priority channel.

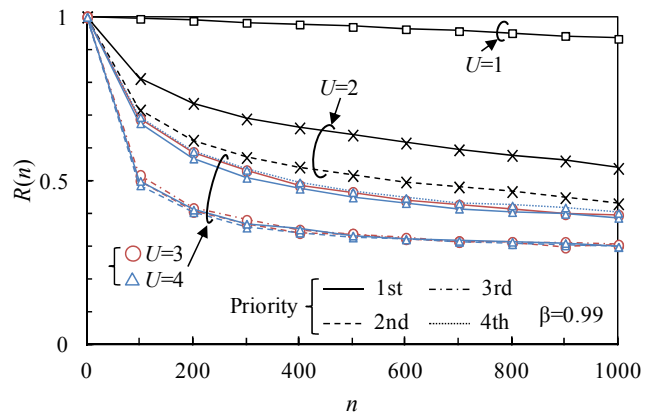
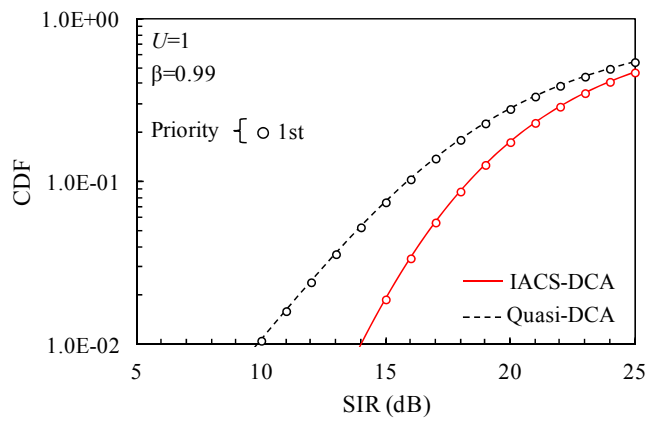


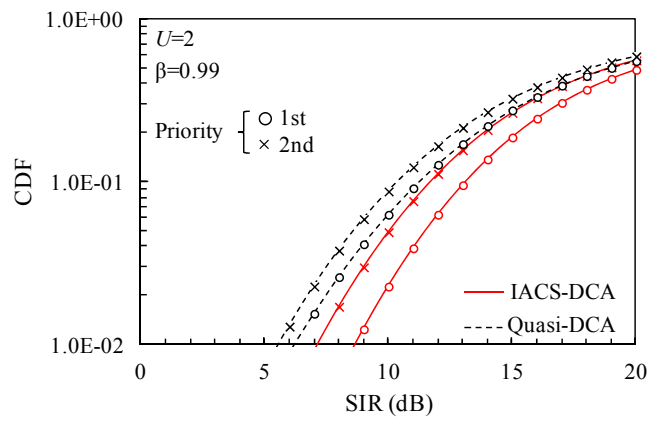
Fig. 5. Autocorrelation of each priority channel.

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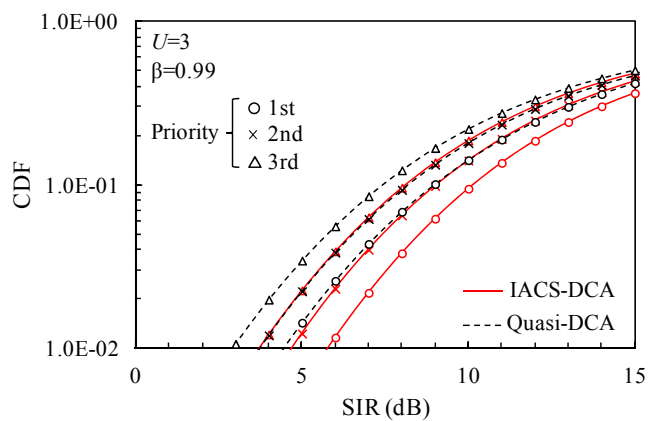
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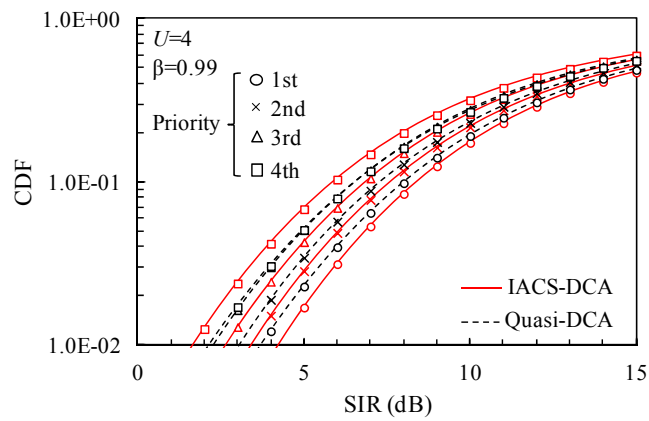
(a)  $U=1$



(b)  $U=2$



(c)  $U=3$



(d)  $U=4$

Fig. 6. CDF of SIR comparison.