Transmit Power Control Suitable for Interference-Aware Channel Segregation Based Dynamic Channel Assignment

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Abstract—**Since the number of available channels is limited, the same channel needs to be reused. Therefore, the co-channel interference (CCI) limits the transmission quality. The channels should be reused so that the CCIs received at all access points (APs) or base stations (BSs) are minimized. Our recently proposed interference-aware channel segregation based dynamic channel assignment (IACS-DCA) can form a stable channel reuse pattern which mitigates the CCI in a distributed manner. An additional use of transmit power control (TPC) can further reduce the CCI. In this paper, we propose a signal-to-interference power ratio (SIR) based TPC scheme suitable for IACS-DCA. We show, by computer simulation, that the IACS-DCA with SIR based TPC forms a stable channel reuse pattern and further improves the outage probability of signal-to-interference-plus-noise power ratio (SINR).**

Keywords—transmit power control; channel segregation; dynamic channel assignment; co-channel interference

I. 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). It is important to reuse the same channel so as to minimize the co-channel interferences (CCIs) received at all APs or BSs. However, in wireless local area network (WLAN), most of AP measures the CCI levels on the available channels and selects the best channel having the lowest CCI only when powered on (in this paper, this is referred to as the quasi-dynamic channel assignment (DCA)). However, the CCI changes in time after AP is powered on, and therefore the channel selected by quasi-DCA cannot be the best all the time.

In order to adapt to the changing CCI environment, DCA [1]-[3] needs to be employed. An application of DCA to wireless networks has been studied extensively in the literature [4]-[6]. One promising DCA is channel segregation based DCA (CS-DCA) [7],[8]. Recently, we proposed an interference-aware CS-DCA (IACS-DCA) [9]. In the IACS-DCA, each AP periodically computes the average CCI powers (obtained from past CCI measurements) on all available channels. The channel having the lowest average CCI power is selected. It was shown that IACS-DCA can form a stable channel reuse pattern in a distributed manner and mitigate the CCI compared with the quasi-DCA [10].

It is well-known that the transmit power control (TPC) is an effective technique to reduce the CCI [11]-[14]. TPC avoids excessive transmit power to reduce the CCI. The signal-to-interference power ratio (SIR) based TPC was extensively studied for its application to code division multiple access (CDMA) cellular systems [15]-[17]. However, a TPC scheme suitable for the IACS-DCA has not been studied yet.

In this paper, we propose a SIR based TPC scheme suitable for IACS-DCA. We show, by computer simulation, that the IACS-DCA with proposed SIR based TPC forms a stable channel reuse pattern and can further improve the outage probability of signal-to-interference-plus-noise power ratio (SINR).

The rest of this paper is organized as follows. Sect. II describes the proposed SIR based TPC suitable for the IACS-DCA. In Sect. III, we examine by computer simulation the stability of channel reuse pattern and the SINR achievable with the IACS-DCA using the proposed TPC. Sect. IV gives some concluding remarks.

II. PROPOSED SIR BASED TPC

We assume wireless networks with time division duplex (TDD), in which each AP is designed to periodically broadcast the beacon containing the CCI information (the average CCI power on the selected channel) and active mobile station (STA) is designed to transmit the uplink signal containing the path loss information in addition to uplink data. It is assumed that the transmit beacon power is known to all STA. STA gets the CCI information by receiving the beacon. Upon the reception of beacon of its AP, STA measures the path loss (including shadowing loss). Using the CCI and path loss information, STA determines its uplink transmit power so that the received signal at its AP meets the required SIR. Meanwhile, AP receives the uplink signal and gets the path loss information of corresponding active STA. The path loss information is used to control the downlink transmit power so that the received signal at its corresponding STA meets the required SIR.

A. CCI table update and channel assignment [9]

Fig. 1 shows a flowchart of the proposed SIR based TPC. As shown in Fig. 1(a), each AP 1-1) measures the uplink instantaneous CCI powers from other STAs on all available channels, 1-2) computes the moving average CCI powers using past CCI measurement results, 1-3) updates the CCI table, 1-4) chooses the channel having the lowest moving average CCI power for use, and 1-5) broadcasts the beacon containing the moving average CCI power. Each AP 1-6) periodically repeats the procedure of 1-1) ~ 1-5).

To compute the moving average CCI powers for all available channels, the first order filtering [18] is used. The number of available channels is denoted by N_{ch}. The moving average CCI power of the m-th AP (AP_m) on the ch-th channel (ch=0~N_{ch}−1) at timeslot t is given as

$$\begin{aligned}\bar{I}_{\mathrm{AP}_m,ch}(t) &= (1-\beta)\cdot I_{\mathrm{AP}_m,ch}(t)+\beta\cdot\bar{I}_{\mathrm{AP}_m,ch}(t-1)\\ &= (1-\beta)\cdot\sum_{i=0}^{t}\beta^i\cdot I_{\mathrm{AP}_m,ch}(t-i)\end{aligned}, \qquad (1)$$

where $I_{\mathrm{AP}_m,ch}(t)$ and β $(0\le\beta<1)$ are the instantaneous CCI power at timeslot t and the filter forgetting factor, respectively. AP looks up the CCI table and chooses the ch_{use}-th channel having the lowest moving average CCI power as

$$ch_{use} = \underset{ch\in[0,N_{ch}-1]}{\arg\min}\{\bar{I}_{\mathrm{AP}_m,ch}(t)\}. \qquad (2)$$

The averaging interval of the first order filtering is given as 1/(1−β) timeslots. If a too small β is used, averaging is not enough and the measured average CCI power varies like a variation of instantaneous CCI power; hence, β≈1 is required [10].

AP broadcasts the beacon containing the moving average CCI power of ch_{use}-th channel, which is given as

$$\tilde{I}_{\mathrm{AP}_m}(t) = \min_{ch\in[0,N_{ch}-1]}\{\bar{I}_{\mathrm{AP}_m,ch}(t)\}. \qquad (3)$$

B. Uplink TPC

As shown in Fig. 1(b), STA 2-1) receives a beacon, 2-2) gets the average CCI power on the received channel, 2-3) measures the received beacon power, and 2-4) computes the path loss (including shadowing loss). The computed path loss between AP_m and m-th STA (STA_m) is given as

$$L_{\mathrm{STA}_m,\mathrm{AP}_m} = P_{\mathrm{t}}^{bcn}/P_{\mathrm{r,STA}_m}^{bcn}, \qquad (4)$$

where P_{t}^{bcn} and $P_{\mathrm{r,STA}_m}^{bcn}$ are the transmit beacon power and received beacon power measured by STA_m, respectively. We assume that the transmit beacon power is known to all STA. STA 2-5) periodically repeats the procedure of 2-1) ~ 2-4).

When 2-6) the uplink transmission is required, STA 2-7) selects the ch_{use}-th channel and 2-8) computes the uplink transmit power. Using the moving average CCI power and the path loss, STA determines its uplink transmit power so that the received signal at its AP meets the required SIR. The uplink transmit power of STA_m is given as

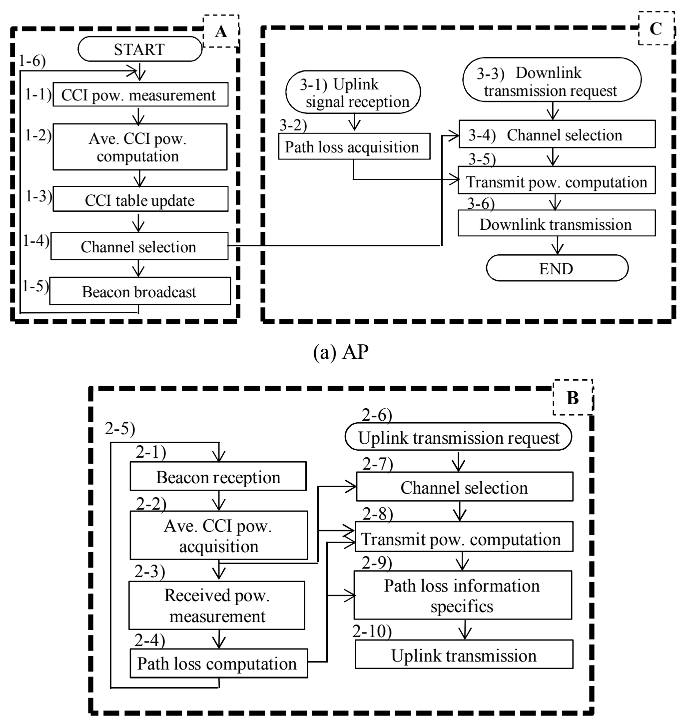
$$\tilde{P}_{\mathrm{t,STA}_m} = \Lambda\cdot\tilde{I}_{\mathrm{AP}_m}(t)\cdot L_{\mathrm{STA}_m,\mathrm{AP}_m}, \qquad (5)$$

where Λ is the target SIR value. STA 2-9) specifies the computed path loss $L_{\mathrm{STA}_m,\mathrm{AP}_m}$ in addition to uplink data and 2-10) transmits the uplink signal.

C. Downlink TPC

Meanwhile, AP 3-1) receives the uplink signal and 3-2) acquires the path loss (including shadowing loss) information from the corresponding active STA. When 3-3) the downlink transmission is required, AP 3-4) selects the ch_{use}-th channel and 3-5) computes the downlink transmit power. Similarly to the uplink, AP determines its downlink transmit power so that the received signal at corresponding STA meets the required SIR. Then, AP 3-6) transmits the downlink signal. The downlink transmit power is given as

$$\tilde{P}_{\mathrm{t,AP}_m} = \Lambda\cdot\tilde{I}_{\mathrm{AP}_m}(t)\cdot L_{\mathrm{STA}_m,\mathrm{AP}_m}. \qquad (6)$$



(b) STA

Fig. 1. Flowchart of proposed SIR based TPC.

III. COMPUTER SIMULATION

Computer simulation was done to examine the stability of channel reuse pattern of proposed scheme and to evaluate the performance of SINR distribution in the network.

Table 1 summarizes the simulation condition. STAs are assumed to be stationary. AP measures the uplink instantaneous CCI power from other STAs and updates the CCI table and the channel at every timeslot. AP periodically broadcasts the beacon containing the moving average CCI power on the selected channel and STA transmits the uplink signal containing the path loss information with the proposed TPC. The perfect measurement of the instantaneous CCI power on each AP is assumed. We consider the TDD system using orthogonal frequency division multiplexing (OFDM) [20]. All STAs transmit packets with a probability of p=1 for uplink and all APs transmit packet with p=1 for downlink.

TABLE I. COMPUTER SIMULATION CONDITIONS

System	No. of co-channel cells	N_{all}=100
	No. of channels	N_{ch}=4
	No. of STAs per cell	U=1
	Transmission probability	p=1.0
	Target SINR	Λ=15~20
Channel	Fading type	Frequency-selective block Rayleigh
	Power delay profile	L=16-path uniform
	Path loss exponent	α=3.5
	Shadowing loss standard deviation	σ=0.0 (dB)
CS-DCA	Forgetting factor of first order filtering	β=0.99
	CCI power measurement	Ideal

A. Network model

Fig. 2 illustrates the network model. N_{all}=100 cells are considered and $N_{\text{int.}}$=36 cells (shadowed region in Fig. 2(a)) are the cells of interest to examine the channel reuse pattern and SIR distribution. As shown in Fig. 2(b), an AP equipped with single antenna is located at the center of each cell and one STA is located randomly in the cell. The distance between adjacent APs is denoted by R_{AP}.

B. Propagation channel model

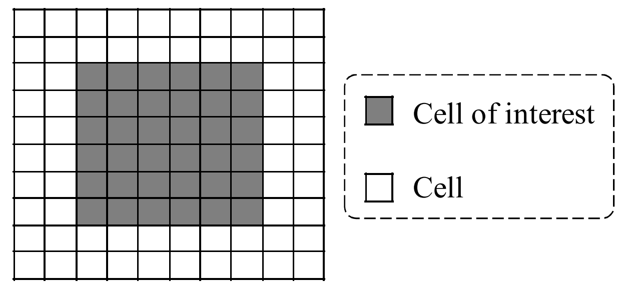
We assume a frequency-selective block Rayleigh fading channel which is composed of L distinct paths. The channel impulse response between AP_m and $\text{STA}_{m'}$ is given by

$$h_{\text{STA}_{m'},\text{AP}_m}(\tau)=\sum_{l=0}^{L-1} h^{(l)}_{\text{STA}_{m'},\text{AP}_m}\delta(\tau-\tau^{(l)}_{\text{STA}_{m'},\text{AP}_m}) \quad (7)$$

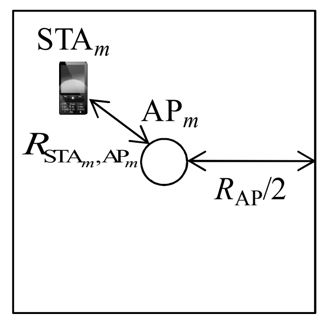
with

$$h^{(l)}_{\text{STA}_{m'},\text{AP}_m}=\sqrt{R^{-\alpha}_{\text{STA}_{m'},\text{AP}_m}\cdot 10^{-\frac{\eta_{\text{STA}_{m'},\text{AP}_m}}{10}}}\cdot\tilde{h}^{(l)}_{\text{STA}_{m'},\text{AP}_m}, \quad (8)$$

where $R_{\text{STA}_{m'},\text{AP}_m}$, α, and $\eta_{\text{STA}_{m'},\text{AP}_m}$ denote the distance between the $\text{STA}_{m'}$ and the AP_m, the path-loss exponent, and the shadowing loss in dB having zero-mean and standard deviation σ, respectively. $\tilde{h}^{(l)}_{\text{STA}_{m'},\text{AP}_m}$ and $\tau^{(l)}_{\text{STA}_{m'},\text{AP}_m}$ are the complex-valued path gain with $E[\sum_{l=0}^{L-1}|\tilde{h}^{(l)}_{\text{STA}_{m'},\text{AP}_m}|^2]$=1 and the time delay of the l-th path between $\text{STA}_{m'}$ and AP_m, respectively.



(a) Cellular structure



(b) Geometry of AP and STA

Fig. 2. Network model.

C. Uplink model

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 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 received signal on k-th subcarrier is expressed as

$$Y_{\text{AP}_m}(k)=\sqrt{2\tilde{P}_{\text{t,STA}_m}}\cdot H_{\text{STA}_m,\text{AP}_m}(k)\cdot x_{\text{STA}_m}(k) + I_{\text{AP}_m}(k)+N_{\text{AP}_m}(k), \quad (9)$$

where $H_{\text{STA}_m,\text{AP}_m}(k)$ and $N_{\text{AP}_m}(k)$ represent the channel transfer function between STA_m and AP_m and the noise component on the k-th subcarrier, respectively. $x_{\text{STA}_m}(k)$ is the data symbol transmitted on the k-th subcarrier. $I_{\mathrm{AP}_m}(k)$ is the CCI component which AP_m receives and expressed as

$$I_{\mathrm{AP}_m}(k)=\sum_{\{u\in U_{\mathrm{AP}_m}:u\neq m\}}\sqrt{2\widetilde{P}_{\mathrm{t,STA}_u}}\cdot H_{\mathrm{STA}_u,\mathrm{AP}_m}(k)\cdot x_{\mathrm{STA}_u}(k)\,, \quad (10)$$

where $U_{\mathrm{AP}_m}\in\{0,1,\ldots,N_{\mathrm{all}}-1\}$ is a set of STA numbers whose channel is the same to the AP_m. Then, the instantaneous CCI power of ch-th channel on AP_m at timeslot t is given by

$$I_{\mathrm{AP}_m,ch}(t)=\frac{1}{N_c}\sum_{k=0}^{N_c-1}\left|I_{\mathrm{AP}_m}(k)\right|^2 . \quad (11)$$

In this paper, ideal measurement of the instantaneous CCI power is assumed.

D. Channel reuse pattern

Fig. 3 shows a one-shot observation of channel reuse pattern formed by the IACS-DCA with proposed SIR based TPC. STA location is shown in Fig. 3(a). The initial channel reuse pattern at time t=0 was generated by assigning channel #0 to all the APs (see Fig. 3(b)). It can be seen from Fig. 3 that the IACS-DCA with proposed SIR based TPC can form a stable channel reuse pattern in a distributed manner.

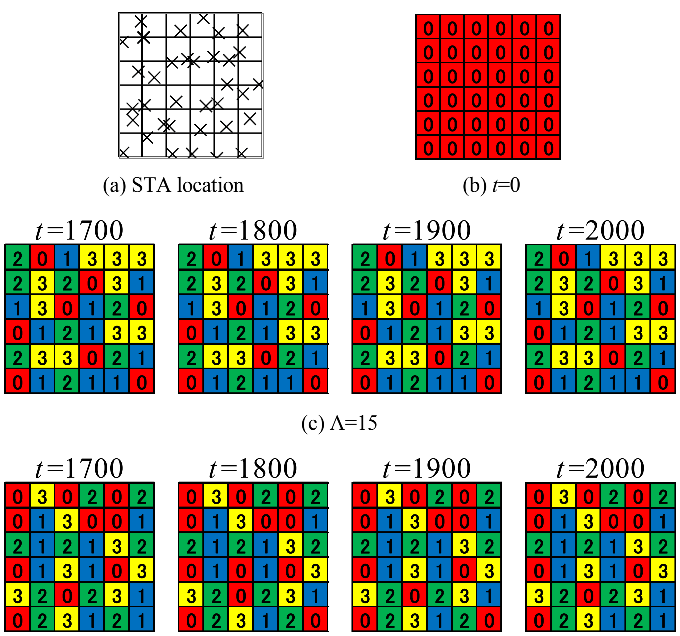


Fig. 3. An example of channel reuse pattern with the IACS-DCA using proposed SIR based TPC.

E. SINR distribution

Fig. 4 plots the probability density function (PDF) of the SINR when using the IACS-DCA with proposed SIR based TPC. The SINR level was measured when t=2000. It can be seen from Fig. 4 that the SINR is distributed near the target value. Table 2 shows the root mean square (RMS) error of measured SINR. It can be seen from Table 2 that the proposed TPC can keep the SINR close to the target value.

Fig. 5 plots the cumulative distribution function (CDF) of the SINR when using the proposed TPC. For comparison, the SINR distributions of the quasi-DCA and the IACS-DCA without TPC under a CCI limited environment are also plotted. It can be seen from Fig. 5 that the proposed TPC improves the outage probability of SINR by increasing the TPC target. For example, the proposed TPC using the target SIR Λ=20(dB) improves the SINR at CDF=10^{-1} by about 4dB and 1dB for uplink and downlink, respectively, compared to the IACS-DCA without TPC.

TABLE II. RMS ERROR OF MEASURED SINR

Target value	RMS error (dB)	
	Λ=15	***Λ=20***
Uplink	1.04	1.67
Downlink	1.32	2.40

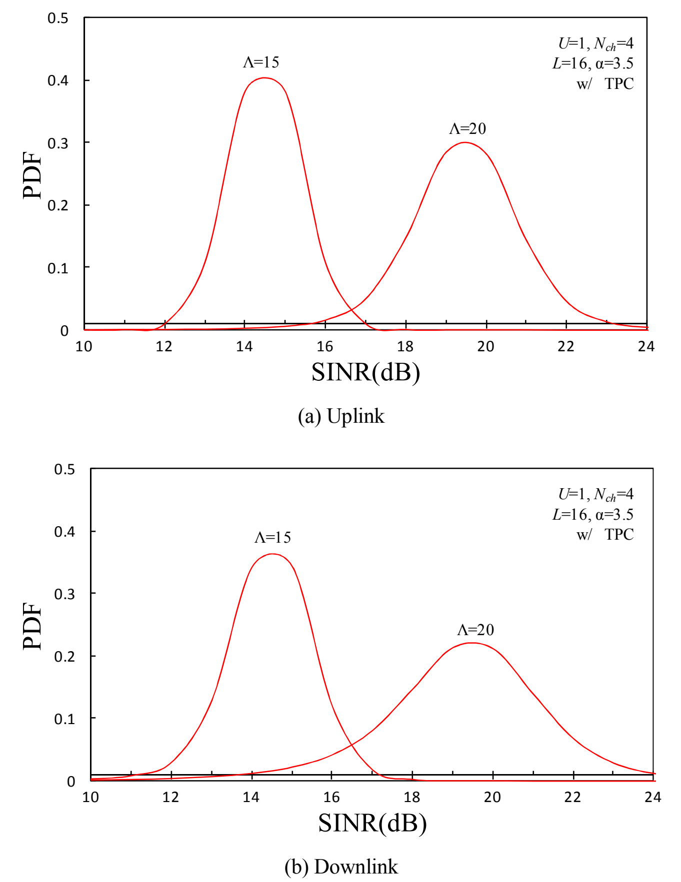
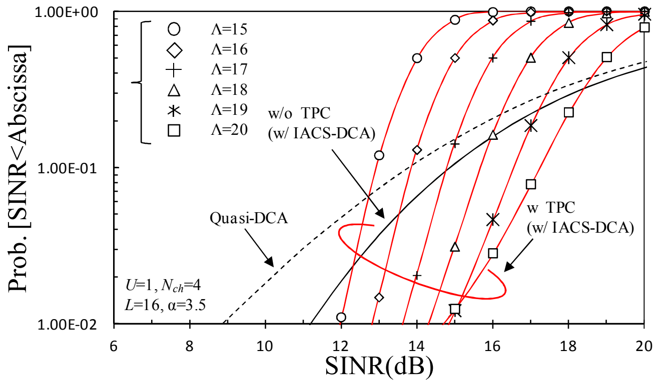
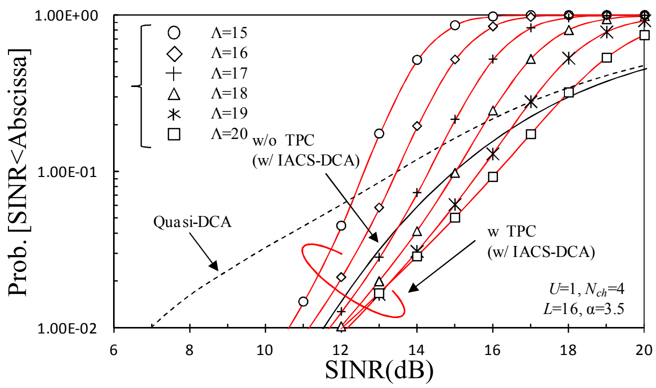


Fig. 4. PDF of SINR.



(a) Uplink



(b) Downlink

Fig. 5. CDF of SINR.

IV. Conclusion

In this paper, we proposed a SIR based TPC scheme suitable for IACS-DCA. We showed, by computer simulation, that even if SIR based TPC is used, the IACS-DCA forms a stable channel reuse pattern in a distributed manner. It was also shown that the proposed TPC using the target SIR Λ=20(dB) improves the SINR at CDF=10^{-1} by about 4dB and 1dB for uplink and downlink, respectively, compared to the IACS-DCA without TPC under a CCI limited environment.

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