

Interference-Aware Channel Segregation Based Dynamic Channel Assignment Using SNR-Based Transmit Power Control

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Abstract—In any wireless network, the same channel must be reused at spatially separated access points (APs) or base stations (BSs) and hence, the co-channel interference (CCI) limits the transmission quality. Therefore, it is very important to reuse the channels so as to minimize the CCIs. We recently proposed an interference-aware channel segregation based dynamic channel assignment (IACS-DCA), which can form a stable channel reuse pattern in a distributed manner. The use of transmit power control (TPC) can avoid the excessive transmit power and hence, contributes to reducing the CCI. An interesting question is if the IACS-DCA can form a stable channel reuse pattern when TPC is used. In this paper, we give an answer to this question and show by computer simulation that a stable channel reuse pattern can be formed even if TPC is used and that the transmit power can be significantly reduced.

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

I. INTRODUCTION

The number of available channels in wireless network is limited. Therefore, the co-channel interference (CCI) limits the transmission quality because the same channel needs to be reused by spatially separated access points (APs) or base stations (BSs). The channels must be reused so as to minimize the CCIs received at all APs. However, in the existing wireless local area network (WLAN), it is designed that when powered on, AP measures the CCI levels on the available channels and selects the best channel having the lowest CCI and continues to use it until powered off (in this paper, this is referred to as the quasi-dynamic channel assignment (DCA)). However, the CCI changes after AP is powered on and therefore, the channel selected by quasi-DCA cannot be the best all the time.

In order to adapt the channel assignment 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 IACS-DCA [9]. Using the IACS-DCA, each AP periodically measures the average CCI powers (obtained from past CCI measurements) on all available channels. The channel having the lowest average CCI power is selected. In [10], we introduced the autocorrelation function of channel reuse pattern, the fairness of channel reusing, and the minimum co-channel AP distance and examined quantitatively the channel reuse pattern formed by the IACS-DCA. It was shown [10] that IACS-DCA can form a stable channel reuse pattern in a distributed manner.

It is well-known that the transmit power control (TPC) is an effective technique to reduce the CCI [11]-[14]. The use of TPC can avoid the excessive transmit power. An interesting question is if the IACS-DCA can form a stable channel reuse pattern when TPC is used. In this paper, we give an answer to this question. We consider a SNR-based TPC for the IACS-DCA and examine the stability of the channel reuse pattern and also how much the transmit power can be reduced.

The rest of this paper is organized as follows. Sect. II overviews the IACS-DCA. In Sect. III, we describe the SNR-based TPC for IACS-DCA. Sect. IV, we examine by computer simulation the stability of channel reuse pattern and the signal-to-interference-plus-noise power ratio (SINR) distribution. Sect. V gives some concluding remarks.

II. OVERVIEW OF IACS-DCA

We assume the time division duplex (TDD). Using IACS-DCA, each AP is designed to periodically measure the uplink CCI power, select the channel whose moving average CCI power is the lowest and broadcast the beacon on the selected channel in order to inform its corresponding mobile station (STA) about which channel to be used.

A. Operation Principle of IACS-DCA [9]

Fig. 1 shows a flowchart of IACS-DCA. As shown in Fig. 1, 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 on the selected channel. 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 [15] 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 ($ch=0\sim N_{ch}-1$) at timeslot t is given as

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

where $I_{AP_m, ch}(t)$ and β ($0 \leq \beta < 1$) 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

$$ch_{use} = \arg \min_{ch \in [0, N_{ch}-1]} \{ \bar{I}_{AP_m, ch}(t) \}. \quad (2)$$

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

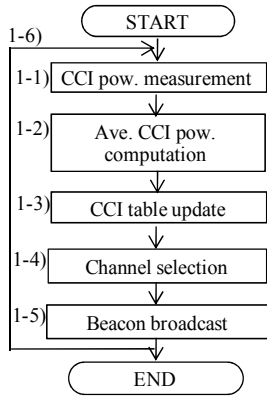


Figure 1. Flowchart of IACS-DCA.

III. SNR-BASED TPC FOR IACS-DCA

As described in Section I, each AP periodically broadcasts a beacon on the selected channel in order to inform its corresponding STA about which channel to be used. Beacon is used for the SNR-based TPC. When a STA receives a beacon of its AP, the STA measures the path loss (including shadowing loss). It is assumed that the transmit beacon power is known to all STAs. Using the measured path loss, the STA determines its uplink transmit power so that the received signal at its AP becomes the required SNR. The STA is designed to transmit the uplink signal containing the path loss

information in addition to uplink data. Meanwhile, the AP receives the uplink signal and gets the path loss information of corresponding active STA. Since the TDD is assumed, the transmit power is the same for both uplink and downlink. AP determines its downlink transmit power so that the received signal at its corresponding STA becomes the required SNR.

A. Uplink TPC

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

$$L_{STA_m, AP_m} = P_t^{bcn} / P_{r, STA_m}^{bcn}, \quad (3)$$

where P_t^{bcn} and P_{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 2-4) periodically repeats the procedure of 2-1) ~ 2-3).

When 2-5) the uplink transmission is required, STA 2-6) selects the ch_{use} -th channel and 2-7) computes the uplink transmit power. Using the path loss, STA determines its uplink transmit power so that the received signal at its AP meets the required SNR. The uplink transmit power of STA_m is given as

$$\tilde{P}_{t, STA_m} = \Gamma \cdot L_{STA_m, AP_m}, \quad (4)$$

where Γ is the target SNR value. STA 2-8) specifies the computed path loss L_{STA_m, AP_m} in addition to uplink data and 2-9) transmits the uplink signal.

B. Downlink TPC

As shown in Fig. 2(b), AP 3-1) receives the uplink signal and 3-2) acquires the path 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 SNR. Since the TDD is assumed, the transmit power is the same for both uplink and downlink. AP 3-6) transmits the downlink signal. The downlink transmit power is given as

$$\tilde{P}_{t, AP_m} = \Gamma \cdot L_{STA_m, AP_m}. \quad (5)$$

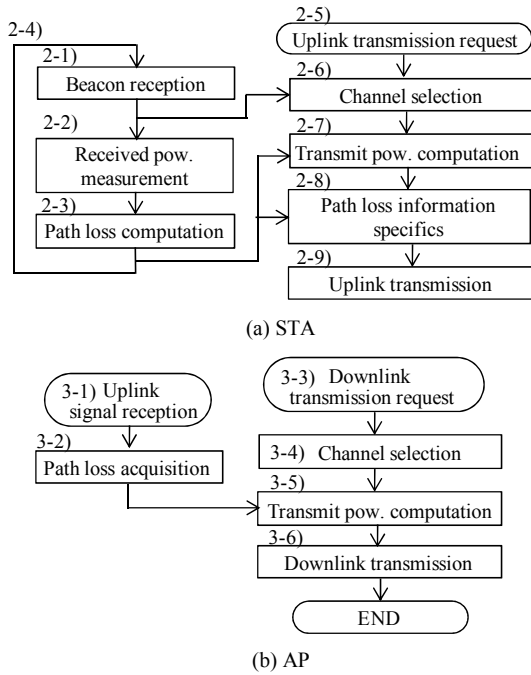


Figure 2. Flowchart of SNR-based TPC.

IV. COMPUTER SIMULATION

Computer simulation was done to examine the stability of the channel reuse pattern and also how much the transmit power can be reduced. The SINR level and the transmit power distribution were measured at $t=2000$.

Table I. summarizes the simulation conditions. 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 on the selected channel and STA transmits the uplink signal containing the path loss information with SNR-based 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) [16]. All STAs transmit packets with a probability of $p=1$ for uplink and all APs transmit packet with $p=1$ for downlink. The theoretical value of instantaneous SINR required for the bit error rate (BER) = 10^{-3} is found to be $\Lambda=9.8$ dB, assuming uncoded transmission using quadrature phase shift keying (QPSK) modulation over an AWGN channel.

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	$p=1.0$
Required SINR		$\Lambda=9.8$ dB
Channel	Fading type	Frequency-selective block Rayleigh
	Power delay profile	$L=16$ -path uniform
	Time delay	$\tau_l=l$ ($l=0\sim L-1$)
	Path loss exponent	$\alpha=3.5$
	Shadowing loss standard deviation	$\sigma=0.0$ dB
IACS-DCA	Forgetting factor of first order filtering	$\beta=0.99$

A. Network model

Fig. 3 illustrates the network model. $N_{all}=100$ cells are considered and $N_{int}=36$ cells (colored regions in Fig. 3(a)) are the cells of interest to examine the channel reuse pattern and SINR distribution. As shown in Fig. 3(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} .

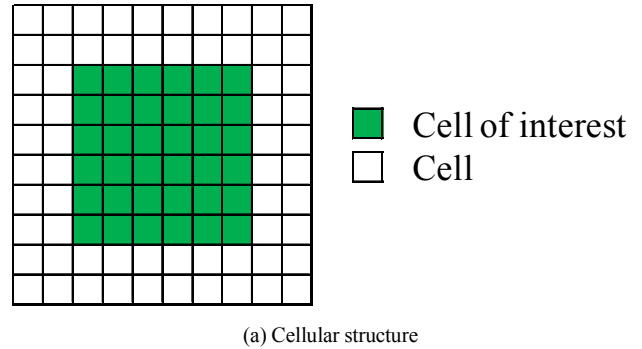


Figure 3. Network model.

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 STA_m is given by

$$h_{STA_m, AP_m}(\tau) = \sum_{l=0}^{L-1} h_{STA_m, AP_m}^{(l)} \delta(\tau - \tau_{STA_m, AP_m}^{(l)}) \quad (6)$$

with

$$h_{STA_m, AP_m}^{(l)} = \sqrt{R_{STA_m, AP_m}^{-\alpha} \cdot 10^{-\frac{\eta_{STA_m, AP_m}}{10}}} \cdot \tilde{h}_{STA_m, AP_m}^{(l)}, \quad (7)$$

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

respectively. The average received signal power P_{r,AP_m} at AP_m from STA_m is given as

$$P_{r,AP_m} = P_{t,STA_m} \cdot R_{STA_m,AP_m}^{-\alpha} \cdot 10^{-\frac{\eta_{STA_m,AP_m}}{10}}, \quad (8)$$

where P_{t,STA_m} is the transmit power. By introducing the normalized distance $r_{STA_m,AP_m} = R_{STA_m,AP_m} / R_{AP}$ and the normalized transmit power $\bar{p}_{t,STA_m} = P_{t,STA_m} \cdot R_{AP}^{-\alpha}$, Eq. (8) can be rewritten as

$$P_{r,AP_m} = \bar{p}_{t,STA_m} \cdot r_{STA_m,AP_m}^{-\alpha} \cdot 10^{-\frac{\eta_{STA_m,AP_m}}{10}}. \quad (9)$$

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

$$Y_{AP_m}(k) = \sqrt{2\tilde{P}_{t,STA_m}} \cdot H_{STA_m,AP_m}(k) \cdot x_{STA_m}(k) + I_{AP_m}(k) + N_{AP_m}(k), \quad (10)$$

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

$$I_{AP_m}(k) = \sum_{\{u \in U_{AP_m}, u \neq m\}} \sqrt{2\tilde{P}_{t,STA_u}} \cdot H_{STA_u,AP_m}(k) \cdot x_{STA_u}(k), \quad (11)$$

where $U_{AP_m} \in \{0, 1, \dots, N_{all}-1\}$ is a set of STA numbers whose channel is the same to the AP_m . In this paper, AP measures the instantaneous CCI power when its STA does not transmit on the channel. The measured instantaneous CCI power of ch -th channel on AP_m at timeslot t can be given as

$$I_{AP_m,ch}(t) = \frac{1}{N_c} \sum_{k=0}^{N_c-1} |I_{AP_m}(k) + N_{AP_m}(k)|^2. \quad (12)$$

D. Channel reuse pattern

Fig. 4 shows a one-shot observation of channel reuse pattern formed by the IACS-DCA with and without SNR-based TPC. STA location is shown in Fig. 4(a). The initial channel reuse pattern at time $t=0$ was generated by assigning channel #0 to all the APs (see Fig. 4(b)). It can be seen from Fig. 4 that the IACS-DCA with SNR-based TPC can form a stable channel reuse pattern in a distributed manner.

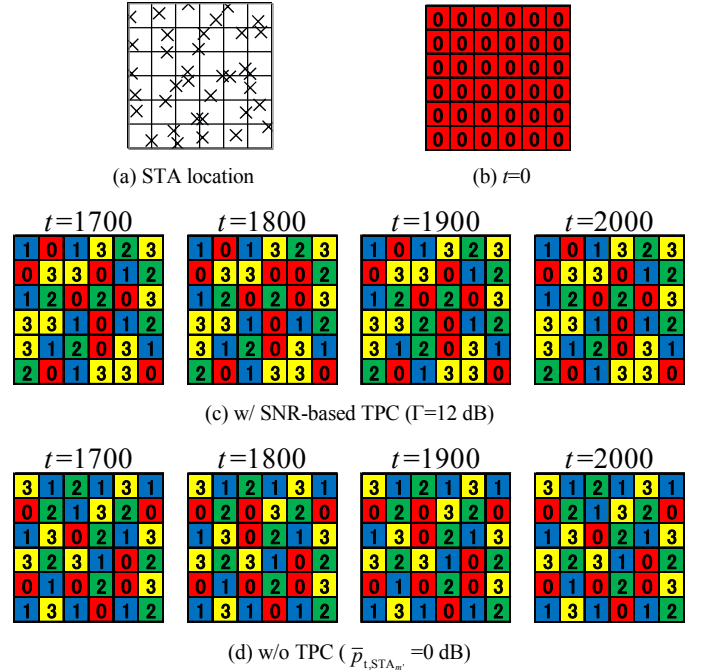


Figure 4. An example of channel reuse pattern of IACS-DCA w/ and w/o SNR-based TPC.

E. SINR distribution

Fig. 5 plots the cumulative distribution function (CDF) of the SINR when the IACS-DCA with SNR-based TPC is used. It can be seen from Fig. 5 that the SNR target Γ for achieving outage probability of 10% at SINR = 9.8 dB is found to be 12 dB. On the other hand, when TPC is not used, the normalized transmit power \bar{p}_t which achieves the same outage probability of 10% is $\bar{p}_t = 0$ dB.

F. Transmit power reduction

Table II. shows the average normalized transmit power of SNR-based TPC when the SNR target $\Gamma=12$ dB. As shown in Table II., the SNR-based TPC can reduce the average transmit power by about 7.5 dB.

Fig. 6 plots the complementary cumulative distribution function (CCDF) of the normalized transmit power. It can be seen from Fig. 6 that the transmit power sometimes increases significantly. For example, the transmit power at CCDF= 10^{-1} is higher by about 6.5 dB than the average transmit power of -7.5 dB. Thus, the high quality power amplifier is required for practical use of the SNR-based TPC.

TABLE II. AVERAGE NORMALIZED TRANSMIT POWER

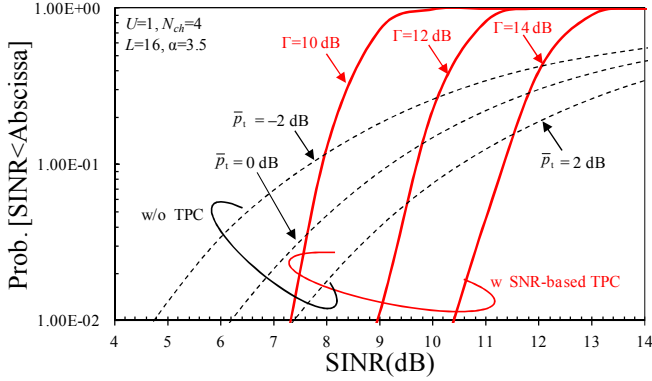
w/ SNR-based TPC	w/o TPC
-7.5 dB	0 dB

V. CONCLUSION

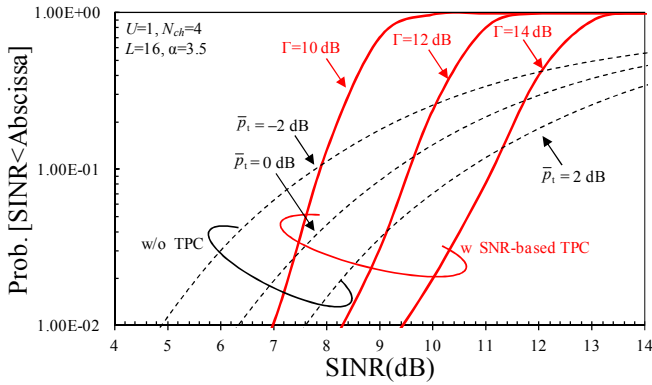
In this paper, we presented a SNR-based TPC for the IACS-DCA. We showed, by computer simulation, that even if SNR-based TPC is used, the IACS-DCA forms a stable channel reuse pattern in a distributed manner. We also showed that the SNR-based TPC can reduce by about 7.5 dB the average transmit power.

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(a) Uplink



(b) Downlink

Figure 5. CDF of SINR.

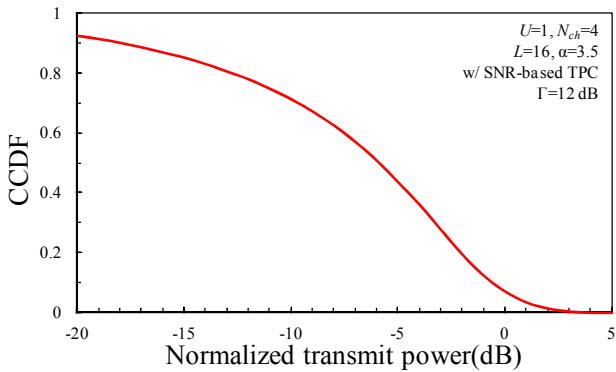


Figure 6. CCDF of normalized transmit power.