Channel Segregation Based Dynamic Channel Assignment for WLAN

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Abstract— **In a frequency reusing wireless local area network (WLAN), the co-channel interference (CCI) environment will change when new access points (APs) join the network. Therefore, the user throughput reduces if the available channels are not properly re-allocated. A newly joined AP is designed to measure the CCI levels on the available channels to select the best channel which experiences the lowest CCI (this is referred to as the conventional channel assignment). However, old APs' channels are not anymore the best since the CCI environment has changed after the new one joined. If each AP periodically measures the CCI environment and re-selects the channel experiencing the lowest CCI, the throughput may improve. This is called the dynamic channel assignment (DCA). In this paper, we apply the channel segregation based DCA (CS-DCA) to WLAN. In order to examine the channel distribution pattern obtained by CS-DCA, we introduce three indicators: the autocorrelation of channel distribution pattern indicating the degree of stability, the deviation of channel reusing, and the minimum co-channel AP distance. We confirm by computer simulation that the CS-DCA can autonomously form a channel distribution pattern which minimizes the CCI at each AP and that the CS-DCA improves the signal-to-interference-ratio (SIR) compared to the conventional scheme.**

Keywords; Channel segregation, dynamic channel assignment, co-channel interference, wireless LAN

I. INTRODUCTION

In wireless local area network (WLAN), the number of available channels is limited. To cover a wide service area, the same channel must be reused by spatially separated access points (APs), thereby producing the co-channel interference (CCI).

In WLAN, a newly joined AP is designed to measure the CCI levels on the available channels to select the best channel which experiences the lowest CCI (this is referred to as the conventional channel assignment). Each AP continues to use its selected channel until it is switched off. However, the throughput performance may degrade since the CCI environment dynamically changes according to the changes in the number of APs and network topology. To avoid this situation, dynamic channel assignment (DCA) can be used. In general, there are two DCA schemes: the centralized DCA [1] and distributed DCA [2]-[4]. The former requires prohibitively high computational complexity and may not be practical in the case of wide-area WLAN. On the other hand, in the latter scheme, each AP measures its CCI environment and selects the best channel according to its own CCI measurement only and hence, it may be suitable for wide-area WLAN.

One promising distributed DCA scheme is channel segregation based DCA (CS-DCA) scheme [3], [4]. In CS-DCA, each AP is equipped with the channel priority table which is updated according to the CCI measurement [4]. Each AP selects the highest priority channel to use. In this paper, we apply CS-DCA to WLAN. In order to examine the channel distribution pattern obtained by CS-DCA, we introduce three indicators: the autocorrelation of channel distribution pattern indicating the degree of stability, the deviation of channel reusing, and the minimum co-channel AP distance. We confirm by computer simulation that the stable channel distribution pattern is obtained and that CS-DCA improves the signal-to-interference-ratio (SIR) compared to the conventional scheme.

This paper is organized as follows. Section II describes the CS-DCA scheme. The WLAN signal model is presented in Sect. III. In Sect. IV, three indicators for examining the channel distribution pattern are introduced. In Sect. V, by computer simulation, we examine the channel distribution pattern to confirm that the CS-DCA is able to form a stable channel distribution pattern and improves the SIR level, compared to the conventional scheme. Section VI gives some concluding remarks and future work.

II. CS-DCA

The number of available channels is denoted by N_{ch}. Figure 1 shows a flowchart of the CS-DCA. In CS-DCA proposed by [4], each AP periodically measures the average CCI power on all available channels and stores the measured average CCI powers in the CCI table. The channel having the lowest average CCI power is assigned. Mobile station (STA) knows the channel to be used according to a beacon signal from AP, and communicates with the AP by using that channel. This scheme leads to reduce the CCI of each AP, thus the transmission quality is improved. To measure the average CCI power for all channels, the first order filtering is used. The average CCI power $\bar{I}_{m,ch}(t)$ on the ch-th channel (ch=0~N_{ch}−1) at time t at the m-th AP is given as

$$\bar{I}_{m,ch}(t) = (1-\beta)\cdot I_{m,ch}(t) + \beta\cdot \bar{I}_{m,ch}(t-1)\ , \tag{1}$$

where $I_{m,ch}(t)$ and β $(0 \le \beta < 1)$ are respectively the instantaneous CCI power at time t and the filter forgetting factor. The traffic changes from time to time and the instantaneous CCI power also varies in time. If a too small β is used, the CCI measurement interval becomes too short and hence, the channel distribution pattern cannot be stable.

The AP checks the CCI table and assigns the ch_{use}-th channel having the lowest average CCI power, where ch_{use} is given as

$$ch_{use} = \arg\min_{ch}\{\bar{I}_{m,ch}(t)\}, ch = 0 \sim N_{ch} - 1 \quad . \tag{2}$$

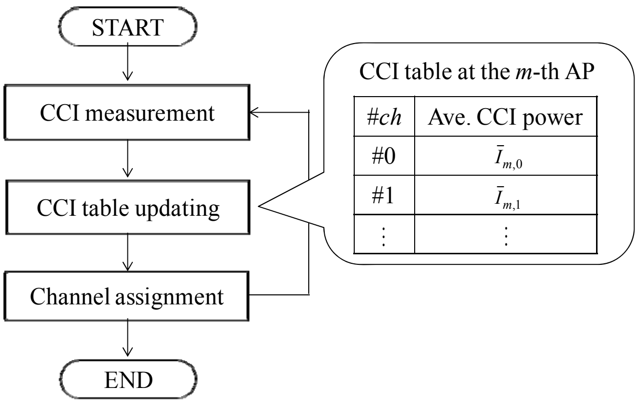

Figure 1. Flowchart of CCI table updating for CS-DCA.

CS-DCA [4] requires the instantaneous CCI power to update the CCI table. The CCI power of N_c blocks can be calculated as

$$P_I = \sum_{k=0}^{N_c-1}\left|Y(k) - \sqrt{\frac{2E_s}{N_cT_s}}H(k)\cdot\hat{x}(k)\right|^2 \quad , \tag{4}$$

where $\hat{x}(k)$ represents the estimate of the data symbol transmitted on the k-th subcarrier. For the channel in which the desired signal is not included in $Y(k)$, we assume $\hat{x}(k)=0$ in Eq. (4). In this paper, we assume that the data estimation is ideal, which means that the instantaneous CCI power measurement on each AP is ideal as well.

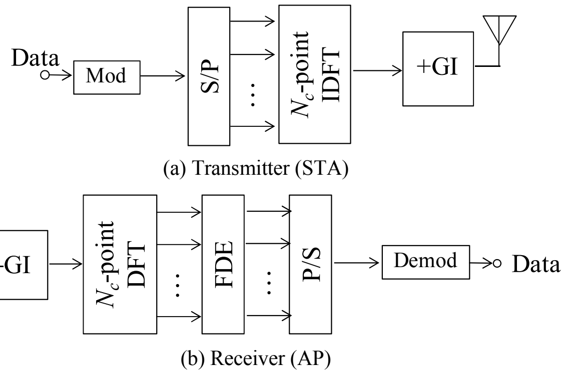

Figure 2. Uplink transmission system model of OFDM.

III. WLAN Signal Model

In this paper, we consider the uplink transmission using orthogonal frequency division multiplexing (OFDM) [5]. Figure 2 illustrates the transmitter and receiver structure of the OFDM transmission using N_c subcarriers. 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 symbols in each block are copied and inserted as a cyclic prefix (CP) in front of the signal block before transmission.

The transmitted OFDM signal block passes through a frequency-selective fading channel. At receiver (AP), after CP removal, the received signal block is decomposed by N_c-point DFT into the orthogonal subcarriers. The k-th subcarrier component is expressed as

$$Y(k) = \sqrt{\frac{2E_s}{N_cT_s}}H(k)\cdot x(k) + N(k) + CCI(k) \quad , \tag{3}$$

where E_s and T_s represent respectively the symbol energy and the data symbol length, and $x(k)$ is the data symbol transmitted on the k-th subcarrier. $H(k)$, $N(k)$, and $CCI(k)$ represent respectively the channel transfer function, the noise component and CCI component. Frequency-domain equalization (FDE) is applied to the frequency-domain received signal. Then, the equalized symbol sequence is de-modulated.

IV. Channel Distribution Pattern

In this section, to examine the channel distribution pattern obtained by CS-DCA, we introduce three indicators: the autocorrelation of channel distribution pattern indicating the degree of stability, the deviation of channel reusing, and the minimum co-channel AP distance.

A. Autocorrelation of channel distribution pattern

We define the autocorrelation of channel distribution pattern as follows: compare the channel distribution pattern of time t with that of time t–n and count the number of APs which use the same channel. We define the autocorrelation $W(n)$ of channel distribution pattern as the number of APs, which use the same channel at time t and time t–n, normalized by the total number of APs:

$$W(n) \equiv E\left[\frac{1}{N_{ap}}\sum_{m=0}^{N_{ap}-1}\sum_{ch=0}^{N_{ch}-1}c_{ch}(m,t)\cdot c_{ch}(m,t-n)\right] , \tag{5}$$

where E[.] denotes the ensemble average operation, N_{ap} represents the total number of APs and $c_{ch}(m,t)$ is a function that gives 1 when m-th AP uses ch-th channel on time t otherwise it gives 0. As the channel distribution pattern approaches a stable condition, $W(n)$ approaches to 1.

B. Fairness index

If the channel reusing is unequal among available channels, the spectrum efficiency degrades. Therefore, it is important to examine the deviation of channel reusing. In this paper, the degree of the deviation of channel reusing is represented by the fairness index [6] and it is defined as

$$F(t) \equiv E\left[\frac{\left(\sum_{ch=0}^{N_{ch}-1} u_{ch}(t) \right)^2}{N_{ch} \cdot \sum_{ch=0}^{N_{ch}-1} u_{ch}(t)^2} \right], \tag{6}$$

where $u_{ch}(t)$ represents the number of APs using the same ch-th channel in an area of interest at time t. $F(t)$ is defined over the range of [1/N_{ch}, 1]. If all channels are fairly assigned, $F(t)$ approaches to 1.

C. Minimum co-channel AP distance

The minimum co-channel AP distance $D(t)$, i.e., the distance between APs which use the same channel, is defined as

$$D(t) \equiv E\left[\frac{1}{N_{ap}} \sum_{m=0}^{N_{ap}-1} \left(\min_{v \in [0, N_{ap}-1]} d_{m,v}(t) \right) \right], \tag{7}$$

where $d_{m,v}(t)$ represents the distance between m-th AP and v-th AP which use the same channel at time t. As the minimum co-channel AP distance gets longer, the CCI gets weaker. In Sect. V, we will investigate by the computer simulation the minimum co-channel AP distance.

V. Computer Simulation

A. Simulation condition

Computer simulation was done to examine the stability of channel distribution pattern of CS-DCA and to evaluate the SIR distribution in the network. Table I summarizes the simulation condition. Figure 3 illustrates the network model. A_{all}=100 cells are considered and $A_{\text{int.}}$=36 cells (shadowed region in Fig. 3) are the cells of interest to examine the channel distribution pattern. As shown in Fig. 4, an AP equipped with the single antenna is located at the center of each cell and a STA is located randomly in the cell. The STAs are assumed to be stationary and transmit its packets with a probability of p=1. The distance between adjacent APs is denoted by R_{AP}. The perfect measurement of the instantaneous CCI power on each AP is assumed.

We assume a frequency-selective Rayleigh fading channel which is composed of L distinct paths. In this paper, we assume that each STA communicates with the corresponding AP in the line-of-sight environment. The interference limited environment is assumed. The channel impulse response between the s-th STA and the m-th AP is given by

$$h_{s,m}(\tau) = \sum_{l=0}^{L-1} h_{s,m,l}\delta(\tau - \tau_{s,m,l}) \tag{8}$$

with

$$h_{s,m,l} = \sqrt{R_{s,m}^{-\alpha}} \cdot \tilde{h}_{s,m,l}, \tag{9}$$

where $R_{s,m}$ and α denote the distance between the s-th STA and the m-th AP and the path-loss exponent, respectively. $\tilde{h}_{s,m,l}$ and $\tau_{s,m,l}$ are the complex-valued path gain with E[$\sum_{l=0}^{L-1} |\tilde{h}_{s,m,l}|^2$]=1 and the time delay of the l-th path between the s-th STA and m-th AP, respectively. The instantaneous received signal power $P_{r,m}$ at the m-th AP from s-th STA is given as

$$\begin{aligned} P_{r,m} &= P_{t,s} \cdot R_{s,m}^{-\alpha} \cdot \sum_{l=0}^{L-1} |\tilde{h}_{s,m,l}|^2 \\ &= \overline{p}_{t,s} \cdot r_{s,m}^{-\alpha} \cdot \sum_{l=0}^{L-1} |\tilde{h}_{s,m,l}|^2 \end{aligned}, \tag{10}$$

where $\overline{p}_{t,s} = P_{t,s} \cdot R_{\text{AP}}^{-\alpha}$ and $r_{s,m}$=$R_{s,m}$/R_{AP} are the normalized transmit power and the normalized distance, respectively.

TABLE I. Numerical and simulation conditions

System	No. of cells	A_{all}=100
	No. of channels	N_{ch}=4
	No. of users per cell	U=1
	Transmission prob.	p=1.0
	Access method	Random access
	Channel estimation	Ideal
DCA	Forgetting factor of first order filtering	β=0.5~0.999
	CCI power measurement	Ideal
Channel	Fading	Frequency-selective block Rayleigh
	Number of paths	L=16
	Power delay profile	Uniform
	Time delay	$\tau_{s,m,l}$=l, l=0~L–1
	Pass loss exponent	α=3.5

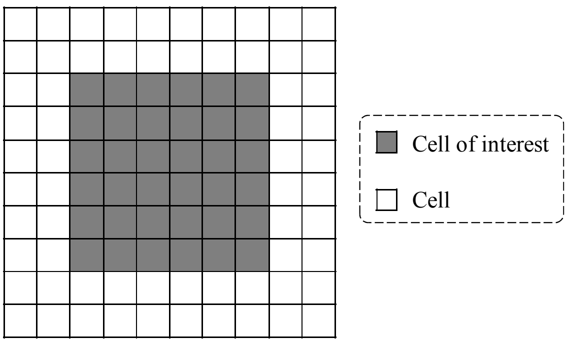

Figure 3. Network model.

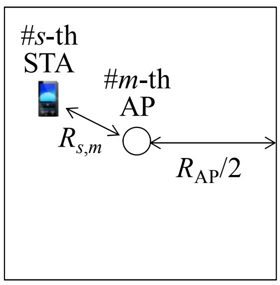

Figure 4. AP distribution

B. *Channel distribution pattern*

Figure 5 shows an example of channel distribution pattern obtained by CS-DCA. STA location is shown in Figure 5 (a). The initial channel distribution pattern at time t=0 was generated by assigning channels randomly to APs (see Fig. 5(b)). It can be seen from Fig. 5 that the stability of pattern depends on the filter forgetting factor β. When β=0.999, the channel distribution pattern changes slowly and becomes stable at around t=1000. When β=0.5, however, the channel distribution pattern is not stable and changes rapidly, i.e., a channel selected by the AP is not always the channel whose CCI is the lowest.

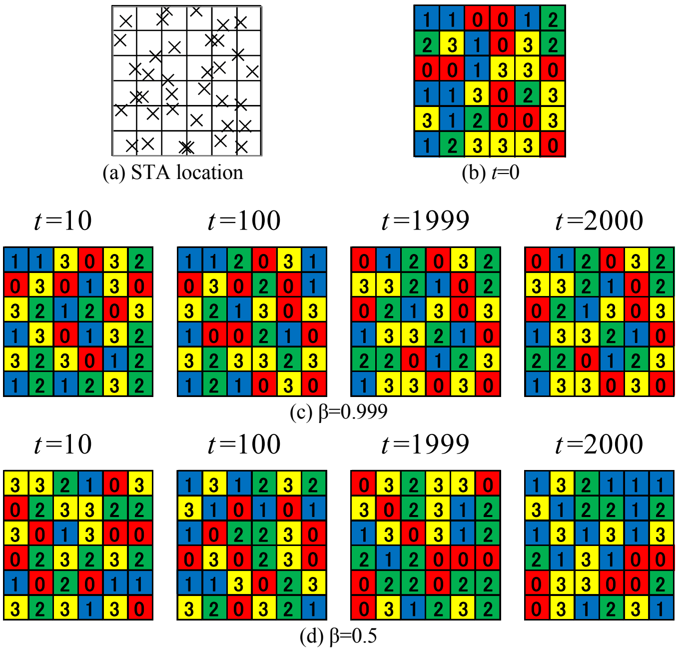

Figure 5. An example of channel distribution pattern with CS-DCA.

Figure 6 plots the autocorrelation $W(n)$ of channel distribution pattern as a function of time separation n with the filter forgetting factor β as a parameter. It can be seen from Fig. 6 that the stability of channel distribution pattern improves when larger β is used. This is because, when β of close to 1 is used, the CCI measurement interval gets longer and the filter output approaches the ensemble average of CCI.

Figs. 7 and 8 show respectively the fairness index $F(t)$ for channel reusing and the minimum co-channel AP distance $D(t)$ normalized by R_{AP} as a function of time t with the filter forgetting factor β as a parameter. It can be seen from Figs. 7 and 8 that when larger β is used, the channels tend to be used equally at APs and the minimum co-channel AP distance gets longer and approaches $D(t)/R_{AP}$=1.42.

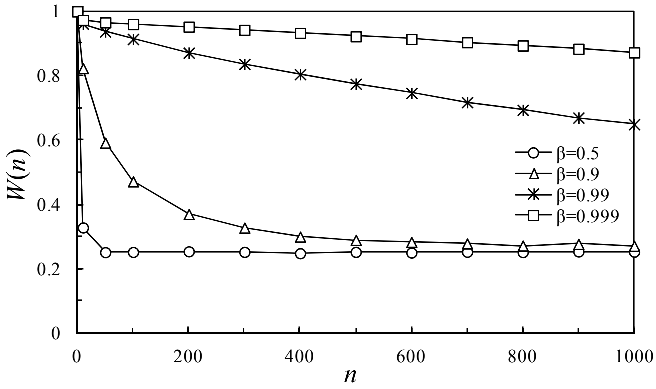

Figure 6. Autocorrelation $W(n)$ of channel distribution pattern.

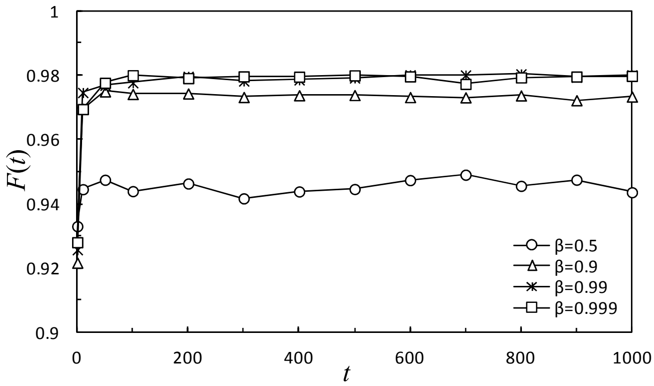

Figure 7. Fairness index $F(t)$ for channel reusing.

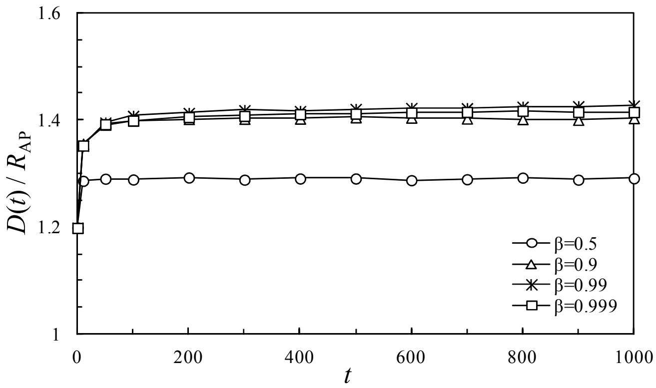

Figure 8. Minimum co-channel AP distance $D(t)/R_{AP}$.

C. *SIR distribution*

Figure 9 plots the cumulative distribution function (CDF) of the SIR when using CS-DCA. The SIR level was measured when t=10000. It can be seen from Fig. 9 that the use of larger β improves the SIR level. This is supported by the fact that the minimum co-channel AP distance gets longer.

Next, we compare the CDFs of CS-DCA and other channel assignment schemes: the random channel assignment (RCA), the conventional scheme, and the fixed channel assignment (FCA) [7]. The CS-DCA using β≈1 improves the SIR level at CDF=10^{-1} by about 1.3dB, compared to the conventional scheme. In spite of the self-organized operation, the performance of CS-DCA can approach to that of the FCA which needs a centralized control.

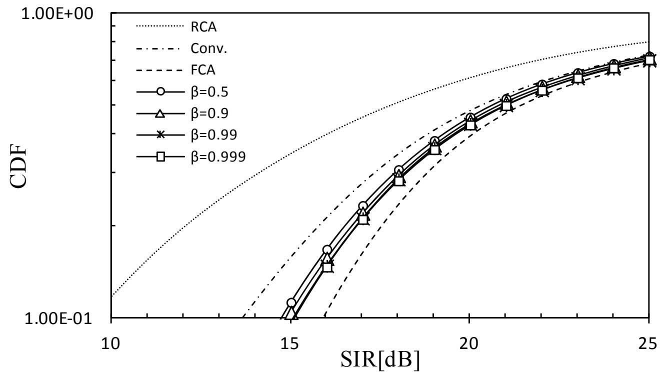

Figure 9. CDF of SIR.

VI. CONCLUSION

In this paper, we applied CS-DCA to WLAN. We examined the channel distribution pattern obtained by CS-DCA and confirmed by computer simulation that the CS-DCA is able to form the stable channel distribution pattern. It was also shown that the CS-DCA improves the SIR level at CDF=10^{-1} by about 1.3dB, compared to the conventional scheme.

In this paper, STAs were assumed to be stationary. However, in practical situations, they move and traffic distribution may dynamically change. The effect of CS-DCA under a dynamically changing traffic distribution is our important topic to study in the future. In this paper, N_{ch}=4 was assumed. How the number of channels affects the channel distribution pattern and the SIR improvement when using CS-DCA is another important topic to study in the future.

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