Impact of Shadowing Correlation on Interference-Aware Channel Segregation Based DCA

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***Abstract*—In wireless networks, the same channel must be reused at different access points (APs). The co-channel interference (CCI) is a predominant factor that limits the transmission quality. Recently, we proposed an interference-aware channel segregation based dynamic channel assignment (IACS-DCA) which forms a channel reuse pattern with low CCI in a distributed manner. In our proposed IACS-DCA, each AP periodically monitors the beacon signals transmitted from other APs and measures the average CCI powers on all available channels to select the best channel to use. However, the actual uplink propagation loss of the co-channel mobile station (STA)-to-AP link is different from that of the co-channel AP-to-AP link due to shadowing. The same is true for the actual downlink shadowing propagation loss. In this paper, we study the impact of shadowing correlation ρ between co-channel AP-to-AP link and actual CCI link on IACS-DCA by computer simulation. It is shown that as ρ decreases, the CCI power experienced at each AP increases, but the 10%-outage signal-to-interference power ratio (SIR) degrades by only 1dB even when ρ=0.4.**

Keywords—channel segregation; dynamic channel assignment; co-channel interference; shadowing correlation

I. INTRODUCTION

The number of available channels is limited in wireless networks and hence, the same channel must be reused by different access points (APs) or base stations (BSs). In this paper, the terminology AP is used. Since the co-channel interference (CCI) limits the transmission quality, the channels must be reused so as to minimize the CCI.

To remedy this problem, we recently proposed interference-aware channel segregation based dynamic channel assignment (IACS-DCA) [1], [2]. In IACS-DCA, each AP periodically monitors beacon signals transmitted from other APs and measures the average CCI powers on all available channels to select the best channel having the lowest average CCI power to use. However, downlink CCI experienced at mobile station (STA) comes from other co-channel APs and the uplink CCI experienced at AP comes from other STAs communicating with other co-channel APs. The actual uplink propagation loss of the co-channel AP's STA-to-AP link may be different from the propagation loss of the co-channel AP-to-AP link due to shadowing. The same is true for the actual downlink propagation loss. Therefore, the actual CCI may be different from the CCI measured using beacon signal.

In this paper, we consider time division duplex (TDD) using orthogonal frequency division multiplexing (OFDM) [3], and study the impact of shadowing correlation ρ on IACS-DCA by computer simulation. We show that by monitoring the beacon signals, IACS-DCA forms a channel reuse pattern which sufficiently suppresses CCI even when ρ=0.4.

The rest of the paper is organized as follows. Section II gives overview of IACS-DCA and gives its mathematical model. In Section III, we show the distribution of signal-to-interference power ratio (SIR) obtained by computer simulation and discuss the impact of shadowing correlation ρ. Section IV offers some concluding remarks.

II. MATHEMATICAL MODEL OF IACS-DCA

A. IACS-DCA

IACS-DCA flowchart is shown in Fig. 1. Each AP is equipped with CCI table. It periodically monitors the beacon signals transmitted from other APs and measures the instantaneous CCI powers on all available channels. Then, each AP computes the average CCI power on each available channel by using past CCI measurement results and updates the CCI table to select the best channel having the lowest average CCI power. After the channel selection, it broadcasts the beacon signal on the selected channel.

B. CCI power measurement

In this paper, discrete time normalized by the CCI measurement time interval is used. There are C available channels and each available channel uses OFDM with N_c subcarriers. We assume an interference-limited channel and a frequency-selective Rayleigh fading channel which is composed of L distinct paths. The impulse response of the propagation channel between transmitter and receiver at time t can be modeled as

$$h(\tau;t)=\sum_{l=0}^{L-1}h_l(t)\delta(\tau-\tau_l)\,, \tag{1}$$

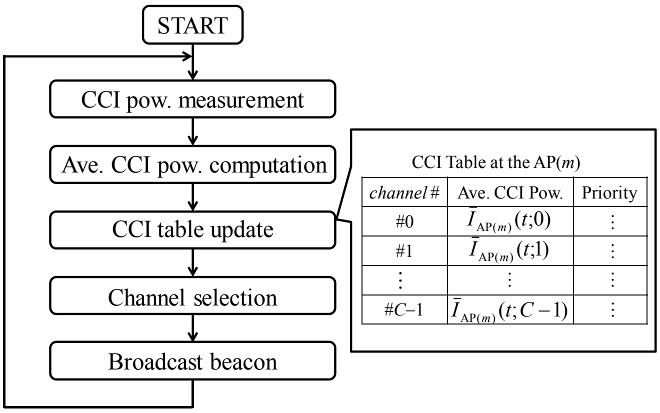

Fig. 1. Flowchart of IACS-DCA.

where $h_l(t)$ and τ_l denote the time-varying complex-valued path gain with $E[\sum_{l=0}^{L-1}|h_l(t)|^2]=1$ (E[.] denotes the ensemble average operation) and the time delay of the l-th path, respectively.

Each AP periodically broadcasts the beacon signal on the selected channel. The instantaneous CCI power $I_{\mathrm{AP}(m)}(t;c)$ measured at AP(m) on the c-th channel (c=0~C−1) at time t is represented as

$$I_{\mathrm{AP}(m)}(t;c)=\sum_{\substack{n\in \mathrm{APG}(c)\\ n\neq m}} p_{\mathrm{AP}(n)}\cdot r_{\mathrm{AP}(m),AP(n)}^{-\alpha}\cdot 10^{-\eta_{\mathrm{AP}(m),\mathrm{AP}(n)}/10} \times\frac{1}{N_c}\sum_{k=0}^{N_c-1}\left|H_{\mathrm{AP}(m),\mathrm{AP}(n)}(t;k,c)\right|^2\,, \tag{2}$$

where APG(c) denotes the AP group which is using the same c-th channel, $p_{\mathrm{AP}(n)}=P_{\mathrm{AP}(n)}\cdot R^{-\alpha}$ is the normalized transmit power of beacon signal of AP(n) with R being the reference distance and α being the path-loss exponent. $r_{\mathrm{AP}(m),\mathrm{AP}(n)}$ and $\eta_{\mathrm{AP}(m),\mathrm{AP}(n)}$ are the normalized distance and the shadowing loss in dB between AP(m) and AP(n), respectively. $H_{\mathrm{AP}(m),\mathrm{AP}(n)}(t;k,c)$ is obtained by the Fourier transform of the channel impulse response between AP(m) and AP(n) at time t and $E[|H_{\mathrm{AP}(m),\mathrm{AP}(n)}(t;k,c)|^2]=1$.

C. Channel selection

In this paper, the first order filtering [4] is used to compute the average CCI power. The average CCI power $\bar{I}_{\mathrm{AP}(m)}(t;c)$ computed at AP(m) on the c-th channel at time t is given as

$$\bar{I}_{\mathrm{AP}(m)}(t;c)=(1-\beta)\cdot I_{\mathrm{AP}(m)}(t;c)+\beta\cdot\bar{I}_{\mathrm{AP}(m)}(t-1;c)\,, \tag{3}$$

where β denotes the forgetting factor. Using the average CCI powers on all available channels, the CCI table is updated for all available channels (c=0~C−1). The channel having the lowest average CCI power is selected as

$$c(m)=\underset{c\in[0,C-1]}{\arg\min}\,\bar{I}_{\mathrm{AP}(m)}(t;c)\,, \tag{4}$$

which is used until the next CCI table updating time t+1. The averaging interval of the first order filtering is given as 1/(1−β). If a too small β is used, averaging is not enough and the measured average CCI power varies like the instantaneous CCI power. Therefore, the channel reuse pattern varies at every CCI table updating time. Hence, β≈1 is recommended [2]. In this paper, β=0.99 is used for the computer simulation.

D. SIR representation

After channel selection, each AP continues to use the selected channel until the next CCI table updating time. For the transmission quality measure in this paper, the block-averaged SIR [5] is used, which is defined as the ratio of the sum of instantaneous signal powers over all subcarriers and the sum of instantaneous CCI powers over all subcarriers. Assuming the synchronous TDD system, the uplink CCI experienced at AP(m) comes from the STAs communicating with their corresponding co-channel APs and is given as

$$I_{\mathrm{AP}(m)}(t)=\sum_{\substack{n\in \mathrm{APG}(c(m))\\ n\neq m}} p_{\mathrm{STA}(n)}\cdot r_{\mathrm{AP}(m),\mathrm{STA}(n)}^{-\alpha}\cdot 10^{-\eta_{\mathrm{AP}(m),\mathrm{STA}(n)}/10} \times\frac{1}{N_c}\sum_{k=0}^{N_c-1}\left|H_{\mathrm{AP}(m),\mathrm{STA}(n)}(t;k,c(m))\right|^2\,, \tag{5}$$

where APG(c(m)) denotes the AP group which is using the same c(m)-th channel and $p_{\mathrm{STA}(n)}=P_{\mathrm{STA}(n)}\cdot R^{-\alpha}$ is the normalized transmit power of STA communicating with AP(n) using the c(m)-th channel. $r_{\mathrm{AP}(m),\mathrm{STA}(n)}$ and $\eta_{\mathrm{AP}(m),\mathrm{STA}(n)}$ are the normalized distance and the shadowing loss in dB between AP(m) and STA(n), respectively. $H_{\mathrm{AP}(m),\mathrm{STA}(n)}(t;k,c(m))$ is obtained by the Fourier transform of the channel impulse response between AP(m) and STA(n) at time t.

On the other hand, the downlink CCI experienced at STA(m) comes from the co-channel APs using the same c(m)-th channel. Similarly to the uplink CCI, we have

$$I_{\mathrm{STA}(m)}(t)=\sum_{\substack{n\in \mathrm{APG}(c(m))\\ n\neq m}} p_{\mathrm{AP}(n)}\cdot r_{\mathrm{STA}(m),\mathrm{AP}(n)}^{-\alpha}\cdot 10^{-\eta_{\mathrm{STA}(m),\mathrm{AP}(n)}/10} \times\frac{1}{N_c}\sum_{k=0}^{N_c-1}\left|H_{\mathrm{STA}(m),\mathrm{AP}(n)}(t;k,c(m))\right|^2\,, \tag{6}$$

where $r_{\mathrm{STA}(m),\mathrm{AP}(n)}$ and $\eta_{\mathrm{STA}(m),\mathrm{AP}(n)}$ are the normalized distance and the shadowing loss in dB between STA(m) and AP(n), respectively. $H_{\mathrm{STA}(m),\mathrm{AP}(n)}(t;k,c(m))$ is obtained by the Fourier transform of the channel impulse response between STA(m)

and AP(n) at time t.

The uplink instantaneous SIR $\lambda_{\mathrm{AP}(m)}(t)$ experienced at AP(m)'s antenna and the downlink instantaneous SIR $\lambda_{\mathrm{STA}(m)}(t)$ experienced at STA(m)'s antenna are given by

$$\begin{cases} \lambda_{\mathrm{AP}(m)}(t)=\dfrac{p_{\mathrm{STA}(m)}\cdot r_{\mathrm{STA}(m),\mathrm{AP}(m)}^{-\alpha}\cdot 10^{-\eta_{\mathrm{STA}(m),\mathrm{AP}(m)}/10}\times\dfrac{1}{N_c}\sum_{k=0}^{N_c-1}\left|H_{\mathrm{STA}(m),\mathrm{AP}(m)}(t;k,c(m))\right|^2}{I_{\mathrm{AP}(m)}(t)} \\ \lambda_{\mathrm{STA}(m)}(t)=\dfrac{p_{\mathrm{AP}(m)}\cdot r_{\mathrm{STA}(m),\mathrm{AP}(m)}^{-\alpha}\cdot 10^{-\eta_{\mathrm{STA}(m),\mathrm{AP}(m)}/10}\times\dfrac{1}{N_c}\sum_{k=0}^{N_c-1}\left|H_{\mathrm{STA}(m),\mathrm{AP}(m)}(t;k,c(m))\right|^2}{I_{\mathrm{STA}(m)}(t)} \end{cases}. \quad (7)$$

III. COMPUTER SIMULATION

The cellular network model of 100 cells is considered for computer simulation as illustrated in Fig. 2. Each AP equipped with a single antenna is located at the center of each cell. Single STA with a single antenna is assumed to be uniformly located within each cell. The distance between adjacent APs is used as the reference distance R. The simulation condition is summarized in Table I. The number of available channels and the number of OFDM subcarriers are assumed to be C=4 and N_c=64. The forgetting factor β to be used for interference averaging is set to β=0.99. 36 cells in the center area are the cells of interest to evaluate the SIR distribution.

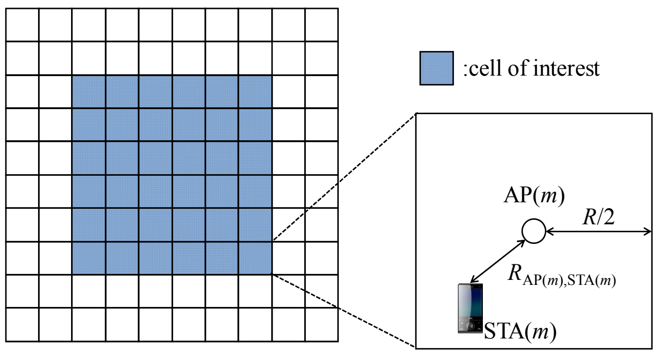

Fig. 2. Cellular model.

TABLE I. COMPUTER SIMULATION CONDITION

Network model	No. of channels	C=4
	Signal transmission	OFDM using N_c=64 subcarriers
Channel model	Path loss exponent	α=3.5
	Shadowing loss	Log-normal with standard deviation σ=5.0 (dB)
	Fading	Rayleigh with L=16-path uniform power delay profile
IACS-DCA	Filter forgetting factor	β=0.99

In each simulation run, STA locations and propagation channel are assumed to be static. The initial channel is set to channel #0 (c=0) for all APs. The SIR measurement is done when t=2000 (i.e., after the channel reuse pattern gets stable). The cumulative distribution function (CDF) of SIR is obtained by conducting the simulation 900 times.

A. Generation of shadowing correlation

As mentioned earlier, each AP periodically monitors beacon signals transmitted from other APs and measures the average CCI powers on all available channels to select the best channel having the lowest average CCI power to use. However, the downlink CCI experienced at STA is from other co-channel APs and the source of uplink CCI experienced at AP is from other STAs communicating with other co-channel APs. The uplink shadowing loss $\eta_{\mathrm{AP}(m),\mathrm{STA}(n)}$ of the co-channel AP's STA to AP link may be different from the co-channel AP-to-AP link $\eta_{\mathrm{AP}(m),\mathrm{AP}(n)}$. The same is true for the downlink. Therefore, it is plausible that the selected channel does not necessarily maximize the SIR if the shadowing correlation between co-channel AP-to-AP link and actual CCI link is low.

The correlation ρ between the shadowing loss $\eta_{\mathrm{AP}(m),\mathrm{STA}(n)}$ of STA(n)-to-AP(m) link and that $\eta_{\mathrm{AP}(m),AP(n)}$ of AP(n)-to-AP(m) link depends on the propagation environment surrounding AP(m). In this paper, for the sake of brevity, the same ρ is assumed for all APs. In the computer simulation, two shadowing losses, $\eta_{\mathrm{AP}(m),\mathrm{STA}(n)}$ and $\eta_{\mathrm{AP}(m),AP(n)}$, having correlation ρ are generated as

$$\begin{cases}\eta_{\mathrm{AP}(m),\mathrm{AP}(n)}=\zeta_0(0,\sigma)\\ \eta_{\mathrm{AP}(m),\mathrm{STA}(n)}=\sqrt{1-\rho^2}\,\zeta_1(0,\sigma)+\rho\eta_{\mathrm{AP}(m),\mathrm{AP}(n)}\end{cases}, \quad (8)$$

where $\zeta_0(0,\sigma)$ and $\zeta_1(0,\sigma)$ are uncorrelated Gaussian variables having zero-mean and standard deviation σ=5.

B. Simulation results

First, the CDF of SIR is presented, followed by the outage SIR. Fig. 3 plots the CDFs of uplink and downlink received SIRs with the shadowing correlation ρ as a parameter. It can be seen from Figs. 3(a) and (b) that as the shadowing correlation ρ decreases, the SIR distribution gets worse. The worst case is when ρ=0. Fig. 4 plots the 90%-, 50%- and 10%-outage SIR when using IACS-DCA with the shadowing correlation ρ as a parameter (the x%-outage SIR is defined as the one which the SIR falls below with probability of x%). For comparison, the outage SIR when using the IACS-DCA based on the actual CCI power measurement [2] is also plotted (note that the achievable SIR is not a function of ρ). It can be seen from Figs. 4(a) and (b) that as the shadowing correlation ρ decreases, the outage SIR of IACS-DCA gets worse. However, even when ρ=0 (which is the worst case), the outage SIR degradation from IACS-DCA based on the actual CCI power measurement is about 2dB. If ρ>0.4, the outage SIR degradation from IACS-DCA based on the actual CCI power measurement is as small as 1dB. It is interesting to note that when compared with IACS-DCA using actual CCI measurement (i.e., the uplink CCI from co-channel STAs is measured), the IACS-DCA using beacon signal monitoring provides slight SIR improvement if ρ>0.7. Any possible reason for this is left as our future study.

IV. Conclusions

In this paper, we studied the impact of shadowing correlation on IACS-DCA. It was shown by computer simulation that as the shadowing correlation ρ between co-channel AP-to-AP link and actual CCI link decreases, the CCI experienced at each AP increases, but the SIR degradation is only about 1dB even when ρ=0.4. It was found that the IACS-DCA using beacon signal monitoring provides slight SIR improvement if ρ>0.7. Any possible reason for this is left as our future study.

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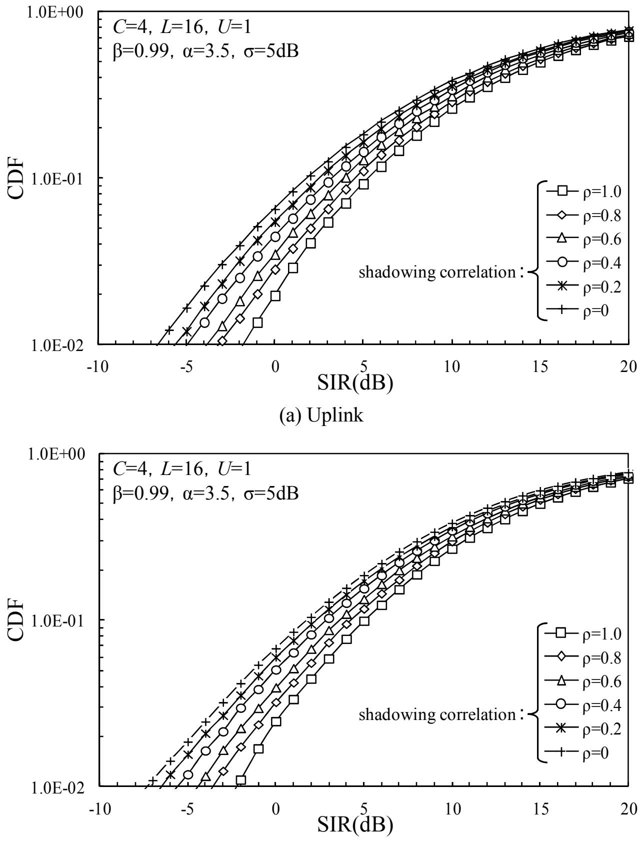

Fig. 3. SIR distribution.

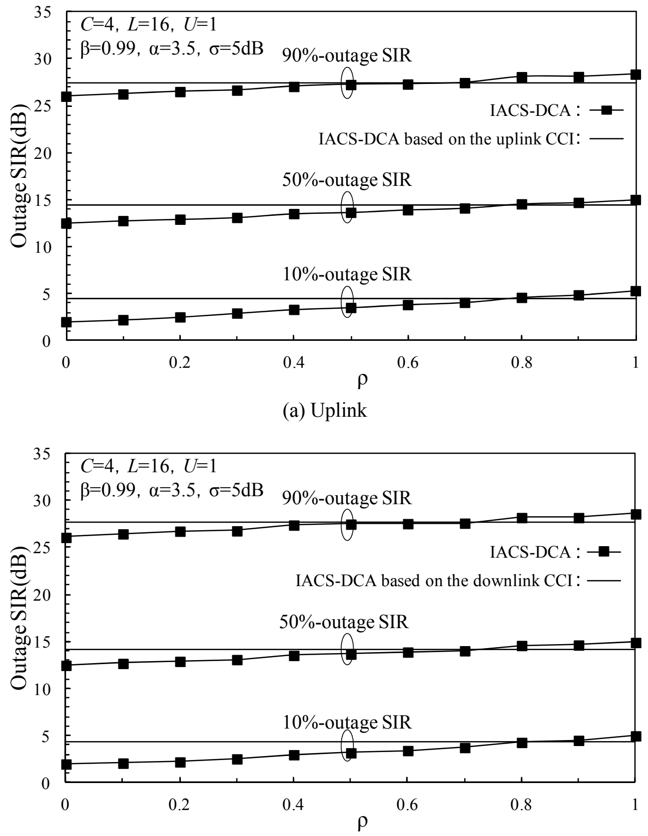

Fig. 4. Outage SIR.