Interference-Aware Channel Segregation for HetNet Using Time- and Frequency-Division Channels

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Abstract—**HetNet is a promising next-generation network. One of the problems in HetNet, when macro-cell base station (MBS) and small-cell BSs (SBSs) share the same radio resource, is the co-channel interference (CCI) between cells, specifically the CCI between macro cell and small cell. Therefore, channel assignment for HetNet is an important issue. Recently the authors proposed interference-aware channel segregation based dynamic channel assignment (IACS-DCA), in which each BS periodically measures the CCI power on all available channels and selects the channel with the lowest average CCI power computed from the past measurements. The channel with the lowest average CCI power is considered not to be used by the neighboring BSs inside and outside of the macro cell of interest, and therefore, IACS-DCA forms a channel reuse pattern with low CCI in a distributed manner. In this paper, we apply IACS-DCA to HetNet using time- and frequency-division channels. We show by computer simulation that IACS-DCA can form a channel reuse pattern with low CCI using time- and frequency-division channels in a distributed manner.**

Keywords—channel segregation; dynamic channel assignment; co-channel interference; heterogeneous network

I. INTRODUCTION

Due to scarce spectrum resources, the number of available channels is limited in wireless networks and therefore, the same channel needs to be reused by different base stations (BSs). Since the transmission quality is limited by the co-channel interference (CCI), the channels must be reused so CCI is minimized at every BS in the network. In addition, CCI environment changes over time. Therefore, the channels should be properly re-assigned according to change of CCI environment. To remedy this problem, dynamic channel assignment (DCA) has been studied [1]-[3]. There are two types of DCA: centralized DCA and distributed DCA. The centralized DCA may not be practical due to its prohibitively high computational complexity and back haul communication [4], [5]. Recently, we proposed an interference-aware channel segregation based DCA (IACS-DCA) [6]-[8], which is categorized into distributed DCA. We showed that in the network using frequency-division channels, IACS-DCA can form a channel reuse pattern with low CCI in a distributed manner [6]-[8]. In IACS-DCA, each BS periodically measures the CCI powers on all available channels to select the best channel having the lowest average CCI power to use.

Heterogeneous network (HetNet), i.e., the combination of several small-cell BSs (SBSs), overlaid by a macro-cell BS (MBS), can deal with exponential increase in wireless data traffic [9]. One of the main problems in HetNet is the CCI between macro cell and small cells when MBS and SBSs share the same radio resource [10]. In this paper, we apply IACS-DCA to HetNet using time- and frequency-division channels. We show by computer simulation that IACS-DCA can form a channel reuse pattern with low CCI in HetNet using time- and frequency-division channels.

The rest of the paper is organized as follows. Section II gives an overview of IACS-DCA. In Section III, we explain the computer simulation model and show the autocorrelation of channel reuse, fairness index, and downlink channel capacity as computer simulation result. Section IV gives some concluding remarks.

II. IACS-DCA

IACS-DCA flowchart is shown in Fig. 1. Each BS is equipped with channel-priority table. It periodically (I) measures the instantaneous CCI powers by monitoring the beacon signal on all available channels. The beacon signal is designed to be periodically transmitted from each BS. Then, each BS (II) computes the average CCI power on all available channels by using past CCI measurement results and (III) updates the channel-priority table to (IV) select the best channel with the lowest average CCI power. After the channel selection, it (V) broadcasts the beacon signal on the selected channel. After channel selection, each BS continues to use the selected channel until the next channel-priority table updating time. Each BS periodically repeats the procedure in (I)~(V).

The channel with the lowest average CCI power is considered not to be used by neighboring BSs and hence, the impact of causing interference to other BSs by using this channel is expected to be small. Therefore, IACS-DCA forms a channel reuse pattern with low CCI in a distributed manner.

A. Simulation model

We show by computer simulation that the channel reuse pattern formed by IACS-DCA reduces the CCI. Fig. 2 shows the HetNet model in this paper. An MBS is located at the center of macro cell. N_{SBS}=10 SBSs are distributed uniformly within one macro cell and U=20 static UEs are assumed to be uniformly located within macro cell. Each UE connects to the BS with the largest received beacon signal power.

III. COMPUTER SIMULATION

The perfectly synchronous time division duplex (TDD) system is assumed. As shown in Fig. 3, we consider C_F=2 frequency-division channels and C_T=3 time-division channels. The channel using c_F-th frequency-domain channel and using c_T-th time-domain channel is represented as $c(c_T,c_F)$. We assume that each BS is designed to periodically transmit the beacon signal on the selected channel and to measure the instantaneous beacon signal power on each of available channels as the instantaneous CCI power for IACS-DCA.

The simulation parameters are summarized in Table I. The number of frequency- and time-division channels are C_F=2 and C_T=3, respectively. Hence, the total number of channels is C_{total}=6.

In each simulation run, the downlink channel capacity measurement is carried out at each updating time. The cumulative distribution function (CDF) of downlink channel capacity is obtained by conducting the simulation run 500 times. We only consider path loss in propagation channel. Based on IACS-DCA, BSs select one channel from available C_{total}=6 channels at each updating time. The initial channel is set to channel $c(1,1)$ for all BSs.

A. Simulation model

The m-th (m=1~N_{MBS}+N_{SBS}) BS and the u-th (u=1~U) UE are represented as BS(m) and UE(u), respectively. Each BS periodically broadcasts beacon signal on the selected channel. The received beacon signal power on BS(m) from BS(n) at updating time t is represented as

$$I_{\mathrm{BS}(m),\mathrm{BS}(n)}(t;c(c_F(n),c_T(n)))=10^{\frac{P_{\mathrm{BS}(n)}}{10}}\cdot 10^{-\frac{l_{\mathrm{BS}(m),\mathrm{BS}(n)}}{10}}, \quad (1)$$

where $c(c_F(n),c_T(n))$ represents the channel which BS(n) selects. $P_{\mathrm{BS}(n)}$ denotes the transmit power of the beacon signal in dB broadcasted from BS(n). $l_{\mathrm{BS}(m),\mathrm{BS}(n)}$ is the propagation loss in dB between BS(m) and BS(n).

B. Average CCI power measurement

For the computation of the average CCI power, the first order filtering with forgetting factor β is used. The average CCI power computed on BS(m) at updating time t is given as

$$\begin{aligned}&\bar{I}_{\mathrm{BS}(m)}(t;c(c_F,c_T))\\&=(1-\beta)\cdot I_{\mathrm{BS}(m)}(t;c(c_F,c_T))+\beta\cdot\bar{I}_{\mathrm{BS}(m)}(t-1;c(c_F,c_T))\end{aligned}. \quad (3)$$

β is the parameter which controls the convergence time of segregation. If a too small β is used, the average CCI power tends to follow the instantaneous CCI power and the channel segregation cannot be done. In this paper, β=0.99 is used [7].

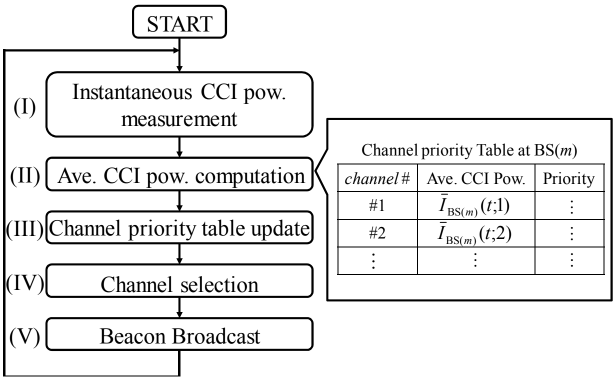

Fig. 1. Flowchart of IACS-DCA.

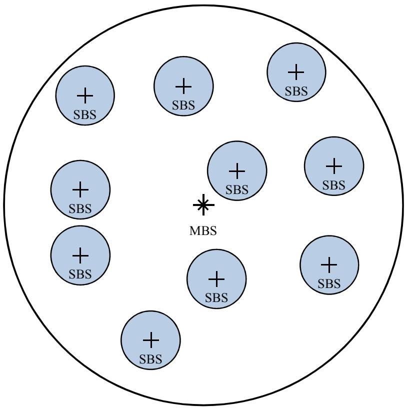

Fig. 2. HetNet model.

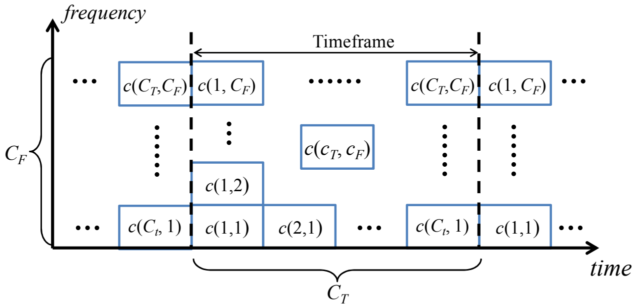

Fig. 3. Channel structure.

TABLE I. COMPUTER SIMULATION CONDITION

Network	No. of MBSs	N_{MBS}=1
	No. of SBSs	N_{SBS}=10
	No. of channels	C_{total}=6
		C_F=2
		C_T=3
	No. of UEs	U=20
	Carrier frequency	2 [GHz]
	Frequency bandwidth	ω=10 [MHz]
	Noise power spectrum density	N_0=−169 [dBm/Hz]
Transmit power	MBS	46 [dBm]
	SBS	30 [dBm]
Path loss [11]	MBS-SBS, MBS-UE	15.3+37.6log$_{10}$(d) [dB]
	SBS-SBS, SBS-UE	30.6+36.7log$_{10}$(d) [dB]
	d: distance between BS and BS or between BS and UE [m]	
IACS-DCA	Filter forgetting factor	β=0.99

C. Autocorrelation of Channel Reuse Pattern

In the time-invariant uniform traffic distribution case, IACS-DCA is expected to form a CCI-minimized stable channel reuse pattern. In this paper, we evaluate the stability of channel reuse pattern by using the autocorrelation function of channel reuse pattern. The autocorrelation function $\Phi(\Delta)$ is defined as the average number of BSs which continuously use the same channel at updating time t and t–Δ, normalized by the total number of BSs. $\Phi(\Delta)$ is given by

$$\Phi(\Delta) \equiv E\left[\frac{1}{N_{\mathrm{MBS}}+N_{\mathrm{SBS}}}\sum_{m\in \mathrm{BSG}}\sum_{c_F=1}^{C_F}\sum_{c_T=1}^{C_T}\left\{\begin{array}{l} q(m,t;c(c_F,c_T)) \\ \cdot\, q(m,t-\Delta;c(c_F,c_T)) \end{array}\right\}\right], \quad (4)$$

where $E[.]$ denotes the ensemble average operation, BSG represents group of all BSs and $q(m,t;c(c_F,c_T))$ is a function that gives 1 when BS(m) uses $c(c_F,c_T)$-th channel at updating time t, otherwise it gives 0. As the channel reuse pattern approaches a stable condition, $\Phi(\Delta)$ approaches to 1.

D. Fairness Index

If a certain channel is reused more frequently in different BSs, the reuse distance of that channel is shorter than those of other channels. Hence, all available channels should be used equally likely. In this paper, a modified Jain's fairness index proposed in [12] is used to evaluate the fairness of channel reuse. The fairness index $F(t)$ is defined as the fairness averaged over all BSs at updating time t and is given as

$$F(t) \equiv E\left[\frac{\left(\sum_{c_F=1}^{C_F}\sum_{c_T=1}^{C_T}\delta(t;c(c_F,c_T))\right)^2}{C_{total}\cdot\sum_{c_F=1}^{C_F}\sum_{c_T=1}^{C_T}\{\delta(t;c(c_F,c_T))\}^2}\right], \quad (5)$$

where $\delta(t;c(c_F,c_T))$ represents the number of BSs using the same $c(c_F,c_T)$-th channel at updating time t. $F(t)$ is defined over the range of $[1/C_{total}, 1]$. $F(t)$ takes a value of 1 when all available channels are used equally likely while it takes a value of $1/C_{total}$ when the same channel is used at all BSs.

E. Downlink channel capacity

For the transmission quality measurement in this paper, downlink channel capacity is used. The downlink channel capacity of the UE(u) connected to BS(m) at updating time t is given as

$$C(t;u) \equiv \frac{\omega}{U_{\mathrm{BS}(m)}}\log_2(1+\lambda_{\mathrm{UE}(u)}(t)), \quad (6)$$

where $U_{\mathrm{BS}(m)}$ represent the number of UEs connected to BS(m). $\lambda_{\mathrm{UE}(u)}(t)$ is the downlink signal-to-interference plus noise power ratio (SINR) at UE(u) and given as

$$\lambda_{\mathrm{UE}(u)}(t) = \frac{10^{\frac{P_{\mathrm{BS}(m)}}{10}}\cdot 10^{-\frac{l_{\mathrm{UE}(u),\mathrm{BS}(m)}}{10}}}{I_{\mathrm{UE}(u)}(t)+(\omega/U_{\mathrm{BS}(m)})N_0}, \quad (7)$$

where $l_{\mathrm{UE}(u),\mathrm{BS}(m)}$ represents the propagation loss in dB between UE(u) and BS(m). $I_{\mathrm{UE}(u)}(t)$ is the received CCI power experienced at UE(u) connected to BS(m) using $c(c_F(m),c_T(m))$-th channel at updating time t and is given as

$$I_{\mathrm{UE}(u)}(t) = \sum_{\substack{n\in \mathrm{BSG}(c(c_F(n),c_T(n)))\\ n\neq m}} I_{\mathrm{UE}(u),\mathrm{BS}(n)}(t;c(c_F(n),c_T(n))), \quad (8)$$

where $I_{\mathrm{UE}(u)\mathrm{BS}(n)}(t;c(c_F(n),c_T(n)))$ represents the received CCI power which comes from BS(n) and is given as

$$I_{\mathrm{UE}(u),\mathrm{BS}(n)}(t;c(c_F(n),c_T(n))) = 10^{\frac{P_{\mathrm{BS}(n)}}{10}}\cdot 10^{-\frac{l_{\mathrm{UE}(u),\mathrm{BS}(n)}}{10}}. \quad (9)$$

F. Simulation results

Fig. 4 shows one-shot observation of channel reuse pattern formed by IACS-DCA. It can be seen from Figs. 4 (a)~(d) that the available channels are fairly used after updating time t=1000. This indicates that IACS-DCA forms the channel reuse pattern with low CCI. It can be also seen from Figs. 4 (c) and (d) that channel reuse pattern is the same at t=1000 and t=2000. This result shows that channel reuse pattern is stable.

Fig. 5 plots the autocorrelation function $\Phi(\Delta)$ of channel reuse pattern as a function of time separation Δ. In Fig. 5, the channel reuse pattern at updating time t=2000 is used as the reference pattern. It can be seen from Fig. 5 that $\Phi(\Delta)$ becomes almost 1 after Δ=1000. This proves that channel reuse pattern formed by IACS-DCA becomes stable after t=1000 times CCI averaging.

Fig. 6 plots the fairness index $F(t)$ of channel reuse as a function of updating time t. It can be seen from Fig. 6 that $F(t)$ becomes close to 1 after t=1000. This provides that all the available channels are fairly used in the network, although IACS-DCA is a distributed algorithm. In addition, we measured the probability that MBS and SBSs select the same channel when updating time t=2000 in each simulation. The probability that MBS and SBSs select the same channel when updating time t=2000 is 0. Therefore, SBSs can avoid the serious CCI from macro cell by IACS-DCA.

Fig. 7 plots the CDF of downlink channel capacity with updating time t as a parameter when the number of UEs is U=20. We observe that downlink channel capacity gets better as longer CCI averaging. Fig. 7 proves that IACS-DCA forms the channel reuse pattern with low CCI.

IV. CONCLUSIONS

In this paper, we studied the IACS-DCA in HetNet using time- and frequency-division channels. We showed by computer simulation that IACS-DCA can form a stable channel reuse pattern with low CCI and the serious CCI from macro cell to small cells, can be avoided in a distributed manner.

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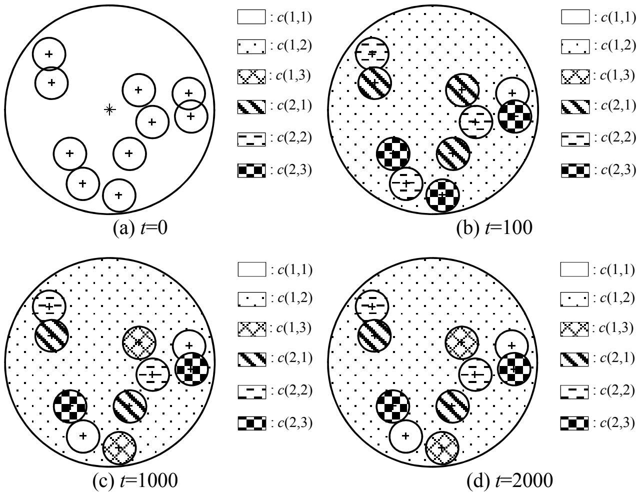

(a) t=0 (b) t=100

(c) t=1000 (d) t=2000

Fig. 4. Observation of channel reuse pattern variation.

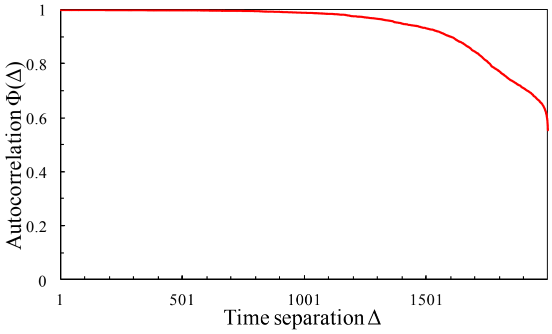

Fig. 5. Autocorrelation of channel reuse.

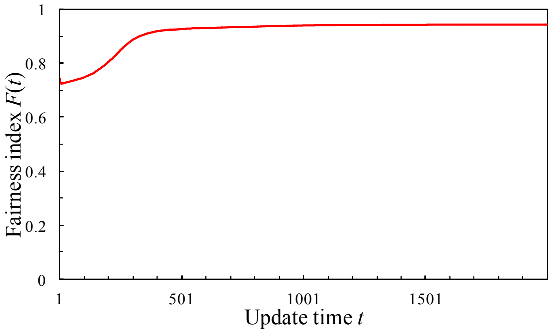

Fig. 6. Fairness index.

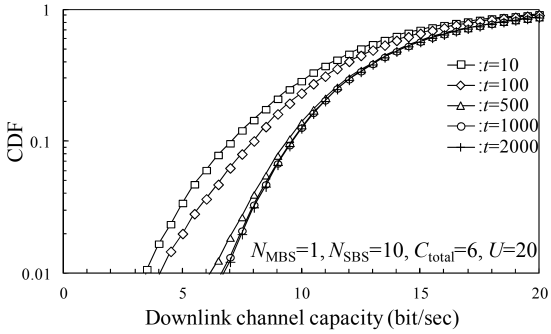

Fig. 7. Downlink channel capacity distribution.