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Interference-aware channel segregation based dynamic channel assignment in HetNet

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Abstract: In this paper, we aim at solving the co-channel interference (CCI) between cells in heterogeneous networks (HetNets), employing an interference-aware channel segregation based dynamic channel assignment (IACS-DCA). To improve the energy efficiency in HetNet, a distributed ON/OFF switching algorithm for BSs is proposed in which each BS selects ON/OFF strategy using game-theory. We combine these two algorithms by using the beacon signal. The beacon signal contains the traffic load information to be used for user equipment (UE) association when BS ON/OFF algorithm is employed and it is used for measuring the instantaneous beacon signal in IACS-DCA. We show by computer simulation that by combining IACS-DCA and distributed ON/OFF switching algorithms for BSs, high transmission quality is achieved.

Keywords: channel segregation, dynamic channel assignment, co-channel interference, heterogeneous network

Classification: Terrestrial Wireless Communication/Broadcasting Technologies

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1 Introduction

Heterogeneous network (HetNet) is a promising network for the 5th generation mobile communications. By offloading traffic from macro base station (MBS) to small BSs (SBSs), traffic per BS can be decreased. Therefore, HetNet can improve the system capacity per area under a given number of available channels. Because of scarce spectrum resources, the number of available channels is limited in wireless networks and therefore, the same channel needs to be reused by different BSs. The same channels can be reused by SBSs even in MBS area by allowing a certain amount of co-channel interference (CCI). CCI is a major problem in HeNet. The CCI between MBS and SBSs becomes serious when MBS and SBSs share the same radio resource. By increasing the number of SBSs, the throughput per user and the capacity per area can be improved. In dense deployment of SBSs, CCI among SBSs themselves becomes a serious problem as well. To solve CCI problem in HetNet, dynamic channel assignment (DCA) can be applied. 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. Recently, we proposed an interference-aware channel segregation based DCA (IACS-DCA) [1, 2, 3], which is categorized into distributed DCA. IACS-DCA can form a channel reuse pattern with low CCI in a distributed manner [1, 2, 3]. We have shown that IACS-DCA can solve CCI problem in HetNet in a distributed manner [3].

Dense deployment of small cell can improve throughput per user and the capacity per area. However, dense deployment of small cell leads to the increase of power consumption of BSs in HetNet. Therefore, a BS ON/OFF switching will be introduced to reduce power consumption of BSs. In [4], a distributed energy-efficient algorithm is proposed in which each BS selects ON/OFF strategy based on the current traffic load and network environment, using a game-theoretic approach. This algorithm is shown to improve the energy efficiency and reduces the overall load in the system comparable to conventional approaches in a distributed manner. According to the network conditions (e.g., power control, user equipment (UE) location and BSs' ON/OFF switching pattern), CCI environment varies over time and channel allocation should cope with this changing environment. Especially, in the dense HetNet, where CCI varies dynamically, radio resource management for BSs becomes complex and difficult. Therefore, a distributed channel assignment method to always minimize the CCI, is required.

In this paper, we study the IACS-DCA using the beacon signal in HetNet, combined with a learning-based game-theoretic BS ON/OFF switching. In learning-based game-theoretic BS ON/OFF switching algorithm, all BSs transmits the beacon signal for UE association. We use this beacon signal for instantaneous CCI measurement in IACS-DCA. As a result, BS doesn't need to transmit any additional signal for channel segregation. We show by computer simulation that the proposed algorithm achieves high transmission quality. The rest of the paper is organized as follows. Section 2 describes the IACS-DCA algorithm. Section 3 presents the system model and ON/OFF switching algorithm. Computer simulation results are brought in Section 4. Finally, Section 5 concludes the paper.

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2 IACS-DCA

In this section we explain briefly four stages of the IACS-DCA Algorithm. Each BS is equipped with a 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. At stage (II), each BS computes the average CCI power on all available channels, using past CCI measurement results and in (III) updates the channel-priority table in order to select the best channel with the lowest average CCI power in (IV). 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)~(IV). 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 minimal. Therefore, IACS-DCA forms a channel reuse pattern with low CCI in a distributed manner.

3 BS ON/OFF switching algorithm

Each BS chooses its strategy (transmission power level). Transmission power of m-th BS, BS(m), is given by

$$P_{\mathrm{BS}(m)}(t) = a_{\mathrm{BS}(m)}(t) \cdot P^{\mathrm{MAX}}_{\mathrm{BS}(m)}, \tag{1}$$

where $a_{\mathrm{BS}(m)}(t) = \{0, 1/3, 2/3, 1\}$ is the transmission power coefficient and $P^{\mathrm{MAX}}_{\mathrm{BS}(m)}$ is the maximum transmission power of m-th BS. Please note that MBS can only select one transmission power coefficient, i.e., $a_{\mathrm{BS}(m)}(t) = 1$ whereas SBSs can select all four available coefficients.

UE association is also decided in this algorithm. If the UE belongs to the set of recently slept BSs, or if it belongs to the set of UEs which have dropped due to overload then it should be assigned to a new BS. In order to connect to a new BS, UEs receive the load estimate of all BSs through the beacon signal and choose the BS to which they want to connect by evaluating an association function.

4 Computer simulation

We show by computer simulation that transmission quality is improved by combining IACS-DCA and BS ON/OFF switching algorithm. An MBS is located at the center of macro cell. N_{SBS} SBSs are distributed uniformly within one macro cell and U static UEs are assumed to be uniformly located within the macro cell. We assume C available frequency channels. Each BS periodically broadcasts a beacon signal on the selected channel containing the load estimate. In IACS-DCA, each BS measures this 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. We only consider path loss in propagation channel. Based on IACS-DCA, BSs select one channel from available $C = 6$ channels at each updating time. The initial channel is set to channel $c = 1$ for all BSs and the initial transmission power coefficient of SBSs is $a_{\mathrm{BS}(m)}(0) = 1$.

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Table I. Computer simulation condition

Network	No. of MBSs	$N_{\mathrm{MBS}} = 1$
	No. of SBSs	$N_{\mathrm{SBS}} = 50$
	No. of channels	$C = 6$
	No. of UEs	$U = 50{\sim}400$
	Carrier frequency	2 [GHz]
	Frequency bandwidth	$\omega = 10$ [MHz]
	Noise power spectrum density	$N_0 = -168$ [dBm/Hz]
	Mean offered traffic per UE	1.8 Mbps
Transmit power	MBS	46 [dBm]
	SBS	30 [dBm]
Path loss	MBS-SBS, MBS-UE	$15.3 + 37.6\log_{10}(d)$ [dB]
	SBS-SBS, SBS-UE	$30.6 + 36.7\log_{10}(d)$ [dB]
	d: distance between BS and BS or between BS and UE [m]	
IACS-DCA	Filter forgetting factor	$\beta = 0.99$

4.1 Simulation model

The m-th ($m = 1{\sim}N_{\mathrm{MBS}} + N_{\mathrm{SBS}}$) BS and the u-th ($u = 1{\sim}U$) UE are represented as BS(m) and UE(u), respectively. The downlink SINR of UE(u) connected to BS(m) at time t is given by

$$\mathrm{SINR}(u,t) = \frac{10^{\frac{P_{\mathrm{BS}(m)}}{10}} \cdot 10^{-\frac{l_{\mathrm{UE}(u),\mathrm{BS}(m)}}{10}}}{I_{\mathrm{UE}(u)}(t) + \omega_{\mathrm{UE}(u)} N_0}, \tag{2}$$

$P_{\mathrm{BS}(m)}$ denotes the transmit power in dB transmitted from BS(m). $l_{\mathrm{BS}(m),\mathrm{BS}(n)}$ represents the propagation loss in dB between UE(u) and BS(m). N_0 is the noise power and $\omega_{\mathrm{UE}(u)}$ is the the set of subcarriers assigned by BS(m) to UE(u). $I_{\mathrm{UE}(u)}(t)$ is the received CCI power experienced at UE(u) connected to BS(m) using c-th channel at time t and is given by

$$I_{\mathrm{UE}(u)}(t) = \sum_{\substack{n \in \mathrm{BSG}(c) \\ n \neq m}} I_{\mathrm{UE}(u),\mathrm{BS}(n)}(t;c), \tag{3}$$

where BSG represents group of BSs using c-th channel and $I_{\mathrm{UE}(u)\mathrm{BS}(n)}(t;c)$ represents the received CCI power of c-th channel which comes from BS(n) at updating time t and is given as

$$I_{\mathrm{UE}(u),\mathrm{BS}(n)}(t;c) = 10^{\frac{P_{\mathrm{BS}(n)}}{10}} \cdot 10^{-\frac{l_{\mathrm{UE}(u),\mathrm{BS}(n)}}{10}}. \tag{4}$$

4.2 Average CCI power measurement

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

$$I_{\mathrm{BS}(m),\mathrm{BS}(n)}(t;c)) = 10^{\frac{P_{\mathrm{BS}(n)}}{10}} \cdot 10^{-\frac{l_{\mathrm{BS}(m),\mathrm{BS}(n)}}{10}}, \tag{5}$$

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

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BS(n). 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

$$\bar{I}_{BS(m)}(t;c) = (1-\beta)\cdot I_{BS(m)}(t;c) + \beta\cdot \bar{I}_{BS(m)}(t-1;c), \quad (6)$$

β is the parameter which controls the convergence time. If a too small β is used, the average CCI power tends to follow the instantaneous CCI power and the channel segregation will not be stable. In this paper, $\beta = 0.99$ is used.

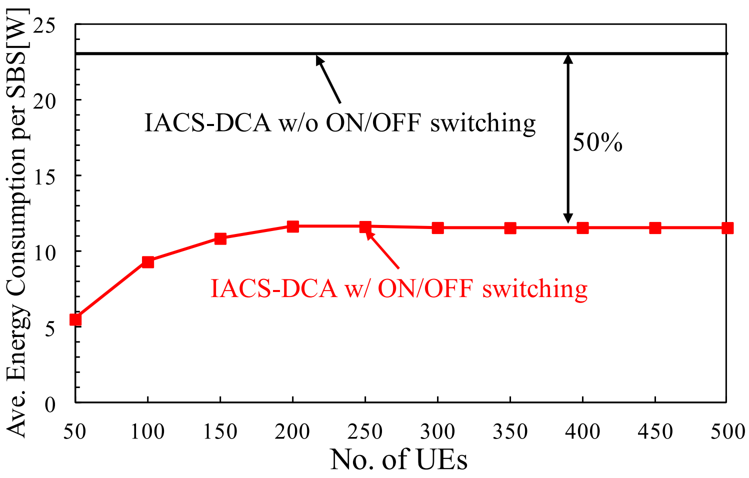

Fig. 1. Ave. energy consumption per SBS.

4.3 Simulation results

Fig. 1 plots average energy consumption per SBS *vs* no. of UE when IACS-DCA and BS ON/OFF switching algorithm are used. For comparison, we also plot average energy consumption per SBS with no. of UEs when only IACS-DCA is applied in HetNet. We observe that average energy consumption per SBS is reduced by BS ON/OFF switching algorithm based on the no. of UE. Even when $U = 500$, 50% of average energy consumption per SBS is reduced.

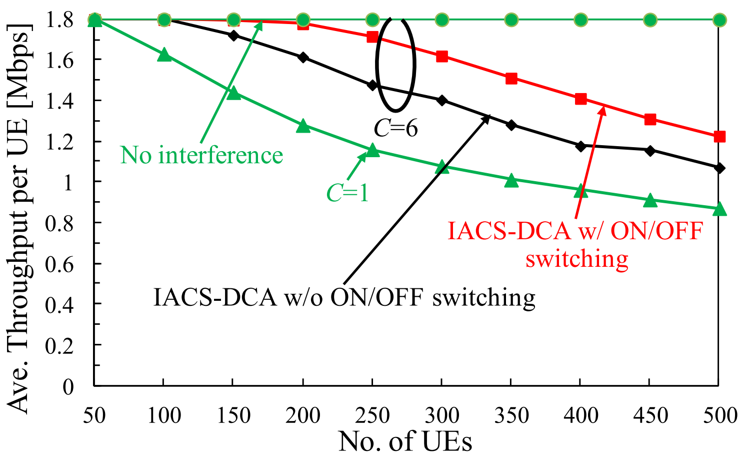

Fig. 2. Ave. throughput per UE.

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Fig. 2 plots the average throughput per UE *vs* no. of UE when IACS-DCA and BS ON/OFF switching algorithm are used. Black line shows the average throughput per UE with no. of UE as a parameter when only IACS-DCA algorithm is applied. Green line represents the case where there is no interference between BSs and when only 1 channel is shared by all BSs. It can be seen from Figs. 7, that the average throughput per UE is improved by combining IACS-DCA and BS ON/OFF switching algorithm. This is because that by ON/OFF switching algorithm the amount of CCI in the network is reduced and IACS-DCA can form a channel reuse pattern with low CCI corresponding to the changes of CCI environment. The result when there is no interference achieves 1.8 Mbps even when $U = 500$. However, as you can see in Fig. 8, average throughput decrease when U is more than 600.

5 Conclusion

In this paper, we studied the IACS-DCA combined with a learning-based game-theoretic BS ON/OFF switching in HetNet. In learning-based game-theoretic BS ON/OFF switching algorithm, all BSs transmits the beacon signal for UE association. We use this beacon signal for instantaneous CCI measurement in IACS-DCA. As a result, BS doesn't need to transmit any additional signal for channel segregation. We showed by computer simulation that IACS-DCA can form a channel reuse pattern in distributed manner, while following the CCI environment changes made by BS ON/OFF switching. Therefore, by combining IACS-DCA and distributed BS ON/OFF switching, higher transmission quality is achieved.

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