

A Base Station Sleep Mode Algorithm Combined with a Channel Interference-Aware Channel Segregation in HetNet

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Abstract The heterogeneous network (HetNet) which consists of several small-cell base stations (SBSs) and an overlaid macro-cell base station (MBS) is a promising next-generation network and achieves very high data rate and energy-efficiency. In this paper, we aim at solving the co-channel interference (CCI) between cells in HetNet, employing an interference-aware channel segregation based dynamic channel assignment (IACS-DCA). In IACS-DCA technique, each BS periodically measures the CCI power on all available channels using the beacon signal and selects the channel with the lowest average CCI. To improve energy efficiency in HetNet, a distributed ON/OFF switching algorithm for BSs is proposed in which each BS selects ON/OFF strategy based on the current traffic load and network environment, 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 UE association when BS ON/OFF algorithm is employed and it is used for measuring the instantaneous beacon signal to be used in IACS-DCA. We show by computer simulation that by combining IACS-DCA and distributed ON/OFF switching algorithms for BSs, high energy-efficiency and high transmission quality is achieved.

Keywords Channel Segregation, Dynamic Channel Assignment, Co-Channel Interference, Heterogeneous Network

1. Introduction

Heterogeneous network (HetNet) is a promising network for the 5th generation mobile communications [1]. HetNet consists of macro base stations (MBSs) and many small cell base stations (SBSs) in each MBS area. By offloading traffic from MBS to SBSs, traffic per BS can be decreased. Therefore, HetNet can improve system capacity per area under the given number of available channels [1]. 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 base stations (BSs). The same channels can be reused by SBSs even in MBS area by allowing a certain amount of CCI. One of the main problems in HetNet is CCI. The CCI between macro cell and small cells becomes serious CCI when MBS and SBSs share the same radio resource [2]. By increasing the number of SBSs, the throughput per user and the capacity per area can be improved. In dense deployment of small cells situation, CCI between SBSs is also serious problem.

To solve CCI problem in HetNet, dynamic channel assignment (DCA) [3]-[5] 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 [6], [7]. Recently, we proposed an interference-aware channel segregation based DCA (IACS-DCA) [8]-[10], which is categorized into distributed DCA. IACS-DCA can form a channel reuse pattern with low CCI in a distributed manner [8]-[10]. 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. 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 [11]. We showed that IACS-DCA can solve CCI problem in HetNet in distributed manner [12].

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. Existing literature has studied a number of problems related to energy efficiency in HetNet, such as BS placement, load balancing, power control, and dynamic BS sleep-wake mechanism [13]-[15]. Although these studies provide good insights into improving energy efficiency, they all rely on a central controller which gathers all network information and makes all decisions. In [16], 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. The proposed 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, 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 energy-efficiency and transmission quality.

The rest of the paper is organized as follows. Section II gives an overview of IACS-DCA and Section III gives system model and an overview of On/OFF algorithm. We explain the computer simulation model and simulation results in Section IV. Section V gives some concluding remarks.

2. IACS-DCA

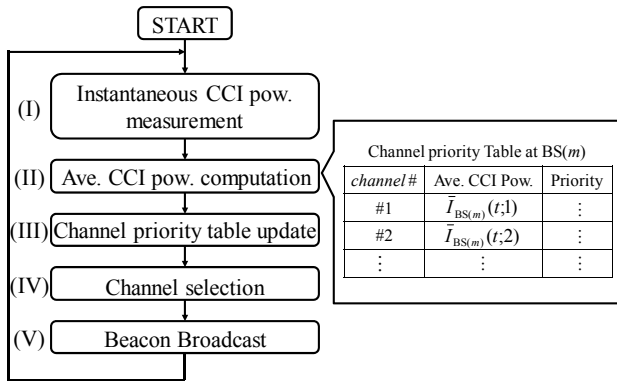


Fig. 1. Flowchart of IACS-DCA.

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.

3. System model

We focus on downlink transmission in HetNet. Fig. 2 shows the HetNet model in this paper. 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 macro cell. Power consumption of BS(m), at time t is given by

$$P_{BS(m)}^{All}(t) = \frac{P_{BS(m)}(t)}{\eta\alpha(1-\alpha_{feed})} + P_{BS(m)}^{Idle}(t), \quad (1)$$

with

$$\alpha = (1-\alpha_{DC})(1-\alpha_{main})(1-\alpha_{cool}), \quad (2)$$

and

$$P_{BS(m)}^{Idle} = \frac{P_{radio} + P_{base}}{\alpha}, \quad (3)$$

where $P_{BS(m)}(t)$ is the transmission power, η is efficiency of power amplifier, $P_{BS(m)}^{Idle}$ is the power consumption in OFF mode. The variables α_{feed} , α_{DC} , α_{main} , and α_{cool} represent the loss fractions of feeder, AC-DC conversion, main supply and cooler system respectively. P_{radio} and P_{base} are the power consumption of radio frequency and baseband units, respectively.

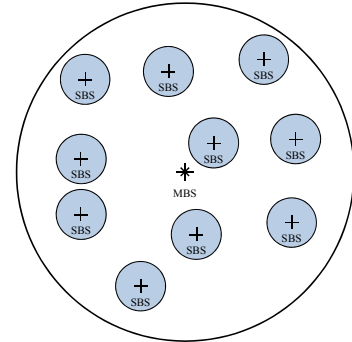


Fig. 2. HetNet model.

3.1. BS ON/OFF switching algorithm[16]

3.1.1. Transmission power

Each BS chooses its strategy (transmission power level), using Fig. 2. Transmission power of m -th BS, BS(m) is given by

$$P_{BS(m)}(t) = a_{BS(m)}(t) \cdot P_{BS(m)}^{MAX}, \quad (4)$$

where $a_{BS(m)}(t) = \{0, 1/3, 2/3, 1\}$ is the transmission power coefficient and $P_{BS(m)}^{MAX}$ is the maximum transmission power of m -th BS. Each transmission power coefficient is decided based on probability distribution $\pi_{BS(m),i}(t-1)$. $\pi_{BS(m),1}(t-1)$, ($i=1,2,3,4$) is the probability which BS(m) choose the $a_{BS(m)}(t)=$

$\{0, 1/3, 2/3, 1\}$ respectively. Please note that MBS can only select one transmission power coefficient, $a_{BS(m)}(t)=1$ whereas SBSs can select all four available coefficients.

3.1.2. Traffic load

We define the instantaneous load density of each BS as the summation of the loads of all individual UEs connected to it according to

$$\rho_{BS(m)}(t) = \sum_{x=1}^{X_{BS(m)}} \frac{\lambda}{\omega' \log_2(1 + \text{SINR}(x, t))}, \quad (5)$$

where λ is packet arrival rate, $\omega' = \omega/C$ is the bandwidth of each BS, C is the number of frequency channels and ω is the total system bandwidth. $\text{SINR}(x, t)$ is the Signal to interference plus Noise Ratio (SINR) of x -th UE at time t . The load of each BS is inversely related to the throughput which provides for the UEs in its service. The average traffic load at time t , $\bar{\rho}_{BS(m)}(t)$, is calculated as

$$\bar{\rho}_{BS(m)}(t) = (1 - l(t))\rho_{BS(m)}(t-1) + l(t)\rho_{BS(m)}(t), \quad (6)$$

where $l(t)$ is the learning rate. In order to ensure system stability, $l(t)$ is chosen such that the load averaging is sufficiently slower than UE association process.

3.1.3. UE Association

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. This association function is based on two metrics, the received signal power and the load condition of each BS. The reason to choose two metrics is to ensure a minimum required QoS for UEs and at the same time to prevent overloading of BSs. The UE's association criteria for BS(m) at time t is formulated according to

$$\text{UE}(m, t) = \arg \max \{P_{BS(m), \text{UE}(n)}(t) / \bar{\rho}_{BS(m)}(t)\}, \quad (7)$$

where $P_{BS(m), \text{UE}(n)}(t)$ is the received signal power of UE(n) from BS(m).

3.1.4. Cost Function

The cost function which simultaneously captures load and energy consumption for BS(m) at time t , $u_{BS(m)}(t)$, is defined by

$$u_{BS(m)}(t) = - \left(\alpha \frac{P_{BS(m)}^{\text{Total}}(t)}{P_{BS(m)}^{\text{MAX}}} + \beta \rho_{BS(m)}(t) \right), \quad \alpha, \beta > 0, \quad (8)$$

where $P_{BS(m)}^{\text{MAX}}$ is the maximum allowed transmission power for BSs in the system, α and β are weighting parameters which define the impact of energy and

load, respectively.

3.1.5. $\pi_{BS(m),i}(t)$ update

Utility estimation, $\bar{u}_{BS(m),i}(t)$, regret, $\hat{r}_{BS(m),i}(t)$ and probability distribution, $\pi_{BS(m),i}(t)$ of i -th strategy for BS(m) at time t are given by

$$\begin{cases} \bar{u}_{BS(m),i}(t) \\ = \bar{u}_{BS(m),i}(t-1) + c(t-1) \cdot \mathbf{1} \cdot \{u_{BS(m)}(t-1) - \bar{u}_{BS(m),i}(t-1)\} \\ \hat{r}_{BS(m),i}(t) \\ = \hat{r}_{BS(m),i}(t-1) + d(t) \{ \bar{u}_{BS(m),i}(t-1) - u_{BS(m)}(t-1) - \hat{r}_{BS(m),i}(t-1) \} \\ \pi_{BS(m),i}(t) \\ = \pi_{BS(m),i}(t-1) + e(t) \{ G_{BS(m),i} \cdot \hat{r}_{BS(m),i}(t-1) - \pi_{BS(m),i}(t-1) \} \end{cases}, \quad (9)$$

with

$$\mathbf{1} = \begin{cases} 1 & (\text{if } a_{BS(m)}(t) = a_{BS(m)}(t-1)) \\ 0 & (\text{if } a_{BS(m)}(t) \neq a_{BS(m)}(t-1)) \end{cases}, \quad (10)$$

and

$$G_{BS(m),i}(\hat{r}_b(t)) = \frac{\exp(\kappa \cdot \hat{r}_{BS(m),i}(t))}{\sum_{i'=1}^4 \exp(\kappa \cdot \hat{r}_{BS(m),i'}(t))}, \quad (11)$$

where $G_{BS(m),i}(\hat{r}_b(t))$ is the Boltzmann-Gibbs (BG) distribution, which is used to encourage those played actions with lower regrets and discourage actions with higher regrets. κ is the temperature parameter. For further information on BG distribution and its role in this game to reach the equilibrium, please refer to [16]. Variables $c(t)$, $d(t)$ and $e(t)$ are learning rates which decay inversely proportional with time and should meet the following conditions:

$$\begin{aligned} \lim_{t \rightarrow \infty} \sum_{m=1}^t c(m) &= +\infty, & \lim_{t \rightarrow \infty} \sum_{m=1}^t d(m) &= +\infty, \\ \lim_{t \rightarrow \infty} \sum_{m=1}^t e(m) &= +\infty, & \lim_{t \rightarrow \infty} \sum_{m=1}^t c^2(m) &< +\infty, \\ \lim_{t \rightarrow \infty} \sum_{m=1}^t d^2(m) &< +\infty, & \lim_{t \rightarrow \infty} \sum_{m=1}^t e^2(m) &< +\infty, \\ \lim_{t \rightarrow \infty} \frac{d(t)}{c(t)} &= 0, & \lim_{t \rightarrow \infty} \frac{e(t)}{d(t)} &= 0. \end{aligned}, \quad (12)$$

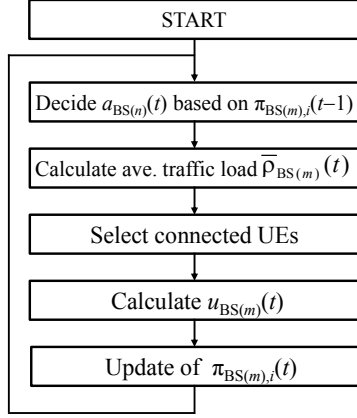


Fig. 3. BS ON/OFF switching algorithm.

4. Computer simulation

We show by computer simulation that energy consumption is reduced and transmission quality is improved by combining IACS-DCA and BS ON/OFF switching algorithm. We assume C available frequency channels. Each BS periodically transmits a beacon signal on the selected channel and measures 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. 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.

TABLE I. COMPUTER SIMULATION CONDITION

Network	No. of MBSs	$N_{MBS}=1$
	No. of SBSs	$N_{SBS}=15$ and 49
	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	180 kbps
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 ($m=1\sim N_{MBS}+N_{SBS}$) 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 as

$$\text{SINR}(u,t) = \frac{10^{\frac{P_{BS(m)}}{10}} \cdot 10^{\frac{I_{UE(u),BS(m)}}{10}}}{I_{UE(u)}(t) + \omega_{UE(u)} N_0}, \quad (13)$$

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

$$I_{UE(u)}(t) = \sum_{\substack{n \in \text{BSG}(c) \\ n \neq m}} I_{UE(u),BS(n)}(t;c), \quad (14)$$

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

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

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

$$I_{BS(m),BS(n)}(t;c) = 10^{\frac{P_{BS(n)}}{10}} \cdot 10^{\frac{I_{BS(m),BS(n)}}{10}}. \quad (13)$$

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

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

$$\begin{aligned} \bar{I}_{BS(m)}(t;c) \\ = (1-\beta) \cdot I_{BS(m)}(t;c) + \beta \cdot \bar{I}_{BS(m)}(t-1;c) \end{aligned} \quad (14)$$

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, $\beta=0.99$ is used [11].

4.3. Simulation results

Fig. 4 shows one-shot observation of channel reuse pattern formed by IACS-DCA when $N_{SBS}=14$. We observe 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 average energy consumption per SBS with no. of UE as a parameter when IACS-DCA and BS ON/OFF algorithm are applied in HetNet. For comparison, average energy consumption per SBS with no. of UE as a parameter when only IACS-DCA algorithm is applied in HetNet is also plotted. It can be seen from Fig. 5 that average energy consumption

per SBS is reduced by BS ON/OFF algorithm based on the no. of UE. Even when $U=400$, 42% of average energy consumption per SBS is reduced in both SBS=15 and SBS=49 cases.

Fig. 6 plots average throughput per BS with no. of UE as a parameter when IACS-DCA and BS ON/OFF algorithm are applied in HetNet. For comparison, average energy consumption per BS with no. of UE as a parameter when only IACS-DCA algorithm is applied in HetNet is also plotted. It can be seen from Figs. 6 that average throughput per BS is improved by combining IACS-DCA and BS ON/OFF algorithm in SBS=49 case. This is because that by ON/OFF 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 change of CCI environment. On the other hand, in SBS=15 case, average throughput per BS decrease. This is because that the transmit power decreases because of ON/OFF algorithm and the number of the UE which can't connect to BSs increases. As a result, the average throughput per UE decreases. This problem can solve by changing the parameter of ON/OFF algorithm.

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, energy consumption is reduced while improving the transmission quality.

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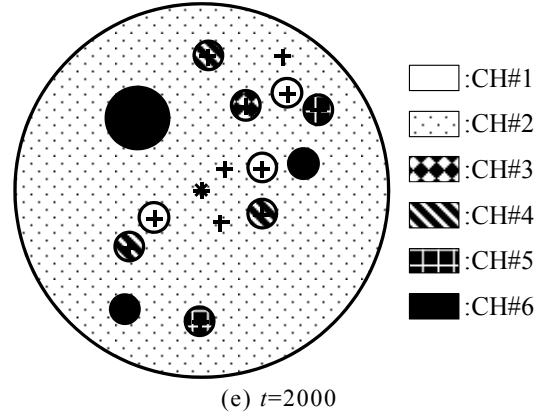
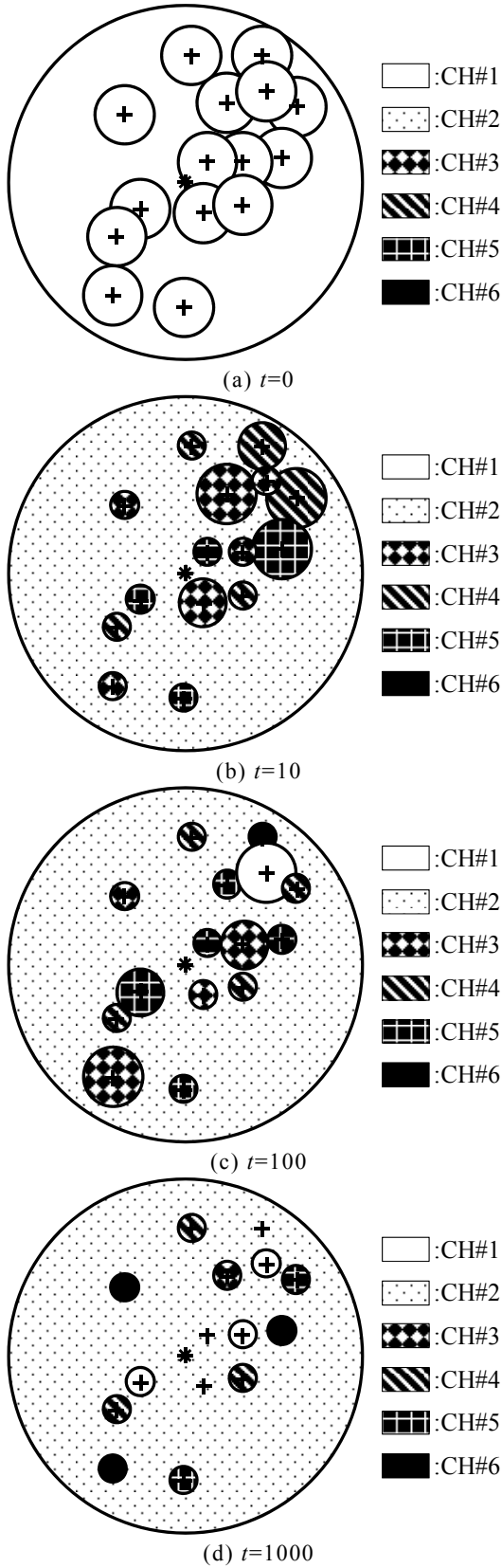


Fig. 4. Observation of channel reuse pattern variation (SBS=15).

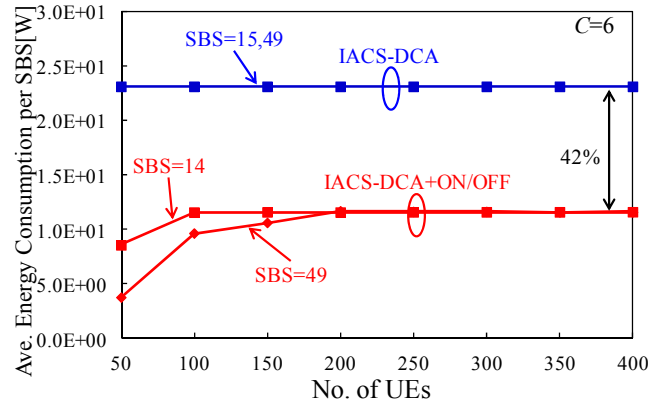


Fig. 5. Average energy consumption per SBS.

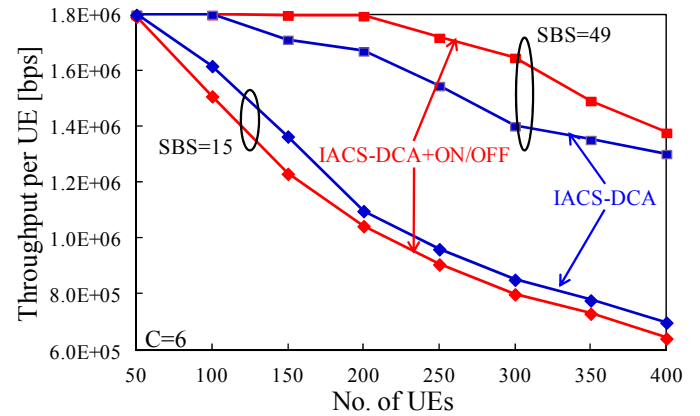


Fig. 6. Average throughput per UE.