Distributed Load Balancing User Association and Self-Organizing Resource Allocation in HetNets

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***Abstract*—The deployment of heterogeneous networks (HetNets) is a promising candidate for the next-generation wireless networks. This is envisioned to deliver higher rate data services in flexible and cost-effective manner. However, in the HetNets, due to the coexistence of various nodes, traffic load variations are more pronounced which requires more dynamic resource management. On the other side, the effective management of resource can significantly impact on the experience of user equipment (UE) and network's performance. In this paper, we address a joint UE association (UEA) and downlink resource allocation problem in the HetNets. In this regard, we propose a UEA policy based on base stations' (BSs') estimated load and signal-to-interference-and-noise-ratio at the location of UE. Furthermore, we apply a self-organizing mechanism to allocate the resource for jointly optimizing the power and channel allocation in a fully distributed way. Our proposed joint UEA and self-organizing resource allocation balances load among BSs and improves the energy efficiency of the network. Simulation results show that our proposed joint UEA and resource allocation yields significant performance gains up to 26.4% and 22% compared to the other benchmark schemes in terms of average energy consumption and average BS load, respectively.**

***Index Terms*—Heterogeneous Network; User Equipment Association; Energy Efficiency; Resource Allocation; Co-Channel Interference.**

I. INTRODUCTION

The explosive growth in smartphone penetration and dramatically increasing demand for higher rate data services, due to the advent of media-hungry devices' applications, pose a rise in the energy consumption of wireless networks. In this respect, the deployment of heterogeneous networks (HetNets) has been viewed as a promising approach [1], [2]. In HetNets, various types of cells with different characteristics, such as size and radio access technologies, coexist to provide a flexible architecture. Typically, these networks consist of macro base stations (MBSs) overlaid with low power and low cost base stations (BSs), such as micro, pico and femto (also referred to as small cell) BSs, and relay BSs which can be deployed by either operator or user [3]. This mixture of BSs can lead to a significant improvement in energy efficiency and spectral efficiency through the reduced distance between the user equipment (UE) and the BS, and offering an improved frequency reuse factor [4], [5].

However, a dense deployment of HetNets can result in a significant increase in energy consumption. On the other hand, the current networks are deployed and operated to carry peak traffic load, whereas BS traffic load dynamically changes in time and space domain. In order to deploy energy efficient HetNets, BS ON/OFF switching and cell breathing methods are two important trends. In cell breathing methods [6], a BS can adaptively control its coverage area according to the traffic load. Using BS ON/OFF switching techniques, a BS can switch to low power consumption modes in light traffic load conditions.

A game theoretic ON/OFF switching approach is proposed in [7], which utilizes a distributed learning algorithm to solve the game and dynamically chooses BS's transmit power. In [8], an energy efficient sleep mode activation scheme controlled by the core network for small cell BSs (SBSs) is developed. In the proposed activation scheme, the SBS with the best channel condition respect to the UE is activated. In [9], network energy consumption is minimized by using a sleep mode technique with considering blocking probability constraint.

Interference management in HetNets is another significant technical issue which needs to be addressed. To cope with this issue, efficient assignment of channels among BSs need to be investigated. Several studies have suggested various channel assignment schemes such as fixed channel assignment, hybrid channel assignment and dynamic channel assignment [10]–[13]. Some literatures have applied the heuristic algorithms such as genetic algorithm and simulated annealing for dynamic channel assignment approaches [14], [15]. In [16], in order to offload UEs from MBS to SBSs, a cell biasing technique is applied. Furthermore, the proposed approach improved system capacity and energy efficiency of the network through power control and frequency reuse in downlink transmission.

On the other side, when a BS switches to an OFF (or sleep) mode, the UEs in its coverage area should try to associate with other active BSs. Moreover, a decision made by a UE to associate with a BS significantly impacts the UE's throughput and other UEs' performance due to traffic load on the BSs. Conventional UE association (UEA) policy is based on received signal strength indication (RSSI) [17]. In [7], the authors consider BS's estimated traffic load as a metric for UEA rule. In [18], a UEA scheme based on a network-wide logarithmic utility maximization problem is proposed. To convert the optimization problem to a convex problem, a relaxed optimization approach is employed. But the radio link quality is governed by the co-channel interference (CCI), i.e. the interference caused by the set of BSs transmitting over the same channel, and it is a major factor of performance degradation. Nevertheless, these works [7], [17], [18] do not consider both BS's estimated load and signal-to interference-and-noise-ratio (SINR) for load balancing and improving the UE's throughput in the UEA rules.

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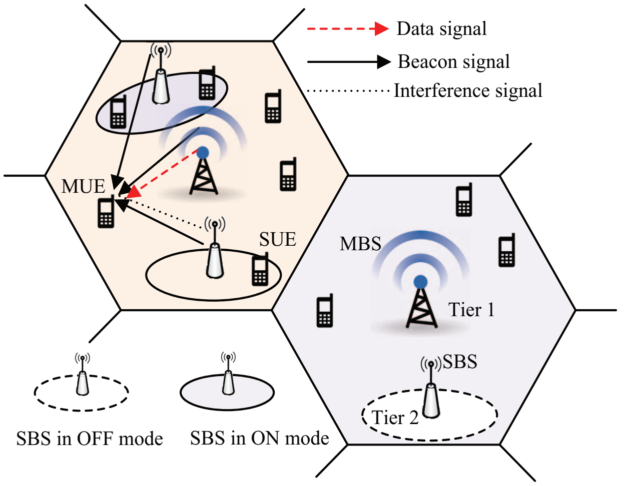

Fig. 1. A typical example of two-tier HetNet. The different channels used by the BSs are displayed by different colored coverage areas.

In this paper, we address a joint UEA and resource allocation. We first propose a UEA policy based on BS's estimated load and SINR at the receiver of UE. In light of this, the BSs periodically broadcast their estimated loads through beacon signals, similar to [19]. Then, for improving the energy efficiency of the network, we implement an ON/OFF switching scheme at the level of BSs using a game theoretic tool that is a straightforward solution. For solving the game, we apply a regret based learning algorithm, in which the BSs learn their environment and choose their transmit power through minimizing their regrets for not having selected other power levels. Furthermore, we employ a distributed channel allocation algorithm implemented at the BSs, in which each BS chooses its channel based on the average CCI power. The BSs can simultaneously choose the same channels. The proposed joint UEA and self-organizing resource allocation attempts to offload UEs from highly loaded BSs to lightly loaded BSs. As a result, it balances load among BSs and improves the quality of service measures in the network such as delay. Moreover, it functions in a fully distributed manner.

The rest of this paper is structured as follows. In Section II, we introduce our system model, including network layout, BS load and BS's power consumption model. Section III describes the proposed joint UEA and self-organizing resource, i.e. power and channel, allocation. The simulation results are presented in Section IV, and finally conclusions are drawn in Section V.

Notations: The scalars and matrices are denoted by regular and boldface symbols, respectively. $|\mathcal{A}|$ denotes the cardinality of set $\mathcal{A}$. $\boldsymbol{X} = [x_{i,j}]_{\mathrm{M}\times\mathrm{N}}$ represents matrix $\boldsymbol{X}$ with dimension M-by-N and the set of elements $x_{i,j}$ which $i = 1, \ldots,$ M and $j = 1, \ldots,$ N. The function $\delta_{(condition)}$ denotes the indicator function which equals 1 if *condition* is true and 0 otherwise.

II. SYSTEM DESCRIPTION

A. Network Model

As shown in Fig. 1, we consider the downlink of a two-tier HetNet with a set of BSs $\mathcal{B}$. Let the set of MBSs $\mathcal{B}_M$ and the set of SBSs $\mathcal{B}_S$ constitute tier 1 and tier 2, respectively, in which $\mathcal{B} = \mathcal{B}_M \cup \mathcal{B}_S$. Without loss of generality, we assume that for each hexagonal coverage area, the MBS is located at the center of area and the SBSs are uniformly located within the coverage of the MBS. The set of UEs $\mathcal{K} = \{1, \ldots, |\mathcal{K}|\}$ are uniformly distributed in the network. The BSs and UEs are also equipped with single antenna. The UEs are allowed to associate with BSs in any tier, i.e. open access scheme. Therefore, UEs can be classified into two types according to the serving BSs, including macro cell UEs (MUEs), the UEs which are associated with the MBSs, and small cell UEs (SUEs), the UEs which are associated with the SBSs. The total bandwidth W is divided into $|\mathcal{Q}|$ orthogonal channels with bandwidth $W/|\mathcal{Q}|$, where $\mathcal{Q} = \{1, \ldots, |\mathcal{Q}|\}$ is the set of available channels. Since the time scale for measuring the total channel gain is much larger than the time scale of fast fading, the total channel gain comprises path loss and lognormal shadow fading. Therefore, the SINR at the receiver of UE $k \in \mathcal{K}$ with respect BS $b \in \mathcal{B}$ transmitting over channel $q_b(t) \in \mathcal{Q}$ at time t is defined by

$$\gamma_{b,k}(t) = \frac{P_b(t)\, I_b(t) g_{b,k}(t)}{\underbrace{\sum_{\acute{b}\in\mathcal{B}\setminus b} L_{\acute{b}}(t)P_{\acute{b}}(t)I_{\acute{b}}(t)g_{\acute{b},k}(t)\ \delta_{(q_b(t)=q_{\acute{b}}(t))} +\sigma^2}_{\text{Interference}}}, \tag{1}$$

where $P_b(t)$ and $g_{b,k}(t)$ denote the transmit power of BS b and the total channel gain between BS b and UE k at time t, respectively. Let $I_b(t)$ be the operation mode indicator of BS b, with each element $I_b(t)$ being equal to 1 if BS b is in ON mode at time t, and equal to 0 otherwise. The load of BS b is denoted by $L_b(t)$ which determines the average resource utilization of BS b. Let σ^2 be the additive white Gaussian noise power at the receiver of the UE. From Shannon's capacity formula, the achievable transmission rate of UE k from BS b at time t is given by

$$R_{b,k}(t) = \frac{W}{|\mathcal{Q}|}\log_2(1+\gamma_{b,k}(t)). \tag{2}$$

We assume that for each UE k, new flows arrive into the system according to an inhomogeneous Poisson point process with arrival rate $\lambda_k(t)$ and mean packet size $\frac{1}{\mu_k(t)}$ at time t. Thus, the total load in the HetNet at time t is expressed by

$$L_{\text{HetNet}}(t) = \sum_{b\in\mathcal{B}} L_b(t), \tag{3}$$

where $L_b(t)$ is the load at BS b which can be represented as

$$L_b(t) = \min\left\{\sum_{k\in\mathcal{K}} a^t_{b,k}\frac{\lambda_k(t)}{\mu_k(t)R_{b,k}(t)}, 1\right\}, \tag{4}$$

where $\frac{\lambda_k(t)}{\mu_k(t)R_{b,k}(t)}$ denotes the load density over the coverage area of BS b. Here, each single binary element $a^t_{b,k} \in \{0,1\}$ represents the association relation between UE k and BS b such that $a^t_{b,k} = 1$ indicates UE k is associated with BS b at time t otherwise $a^t_{b,k} = 0$.

B. Power Consumption Model

The main power consumption components of a BS are power amplifier, radio frequency circuit, baseband unit and other physical infrastructures such as cooling system, DC-DC power supply and main supply. We assume that under low traffic load, the BSs can switch to an OFF mode in order to save power. In OFF mode, the BSs still consume a amount of power for reactivation. Therefore, the BSs operate with different power consumption values in ON (or active) mode and OFF mode. In this respect, we define the set of BSs in ON mode, $\mathcal{B}_{\mathrm{ON}}(t) = \{b | I_b(t) = 1, b \in \mathcal{B}\}$, and the set of BSs in OFF mode, $\mathcal{B}_{\mathrm{OFF}}(t) = \{b | I_b(t) = 0, b \in \mathcal{B}\}$, at each time t. Therefore, depending on the BSs' operation modes, the total power consumed by the BSs in the HetNet over time duration T can be expressed as [19]

$$P_{\mathrm{HetNet}} = \sum_{t=1}^{T} \left(\sum_{b \in \mathcal{B}_{\mathrm{ON}}} P_b^{\mathrm{ON}}(t) + \sum_{b \in \mathcal{B}_{\mathrm{OFF}}} P_b^{\mathrm{OFF}}(t) \right), \tag{5}$$

where

$$P_b^{\mathrm{ON}}(t) = P_b^{\mathrm{OFF}} + \frac{P_b(t)\ I_b(t)}{\eta_b^{\mathrm{PA}} \Lambda (1 - \lambda_b^{\mathrm{Feed}})}, \tag{6}$$

with

$$P_b^{\mathrm{OFF}} = \frac{P_b^{\mathrm{RF}} + P_b^{\mathrm{BB}}}{\Lambda}, \tag{7}$$

and

$$\Lambda = \left(1 - \lambda_b^{\mathrm{DC}}\right) \left(1 - \lambda_b^{\mathrm{MS}}\right) \left(1 - \lambda_b^{\mathrm{Cool}}\right), \tag{8}$$

where $P_b^{\mathrm{ON}}(t)$ and P_b^{OFF} are the consumed power in ON mode and OFF mode by BS *b* at time *t*, respectively. $P_b^{\mathrm{RF}}$and P_b^{BB} denote the power of the radio frequency module and the total power of baseband engine consumed by BS *b*, respectively. η_b^{PA} indicates the power amplifier efficiency of BS *b*. $\lambda_b^{\mathrm{Feed}}$,$\lambda_b^{\mathrm{DC}}$, λ_b^{MS} and $\lambda_b^{\mathrm{Cool}}$ represent losses which are incurred by feeder, DC-DC power supply, main supply and cooling system, respectively.

III. TOWARDS JOINT UE ASSOCIATION AND SELF-ORGANIZING RESOURCE ALLOCATION

In this section, we focus on the joint design of load balancing UEA and resource, i.e. channel and power, allocation problem. In this regard, at each time t, the HetNet can be configured dynamically depending on the transmit power levels vector, $\boldsymbol{P}(t) = [P_b(t)]_{|\mathcal{B}| \times 1}$, the channels vector, $\boldsymbol{Q}(t) = [q_b(t)]_{|\mathcal{Q}| \times 1}$, and the association matrix between the UEs and BSs, $\boldsymbol{A}^t = [a_{b,k}^t]_{|\mathcal{B}| \times |\mathcal{K}|}$. Let $\boldsymbol{A}_b^t = \{k | a_{b,k}^t = 1, k \in \mathcal{K}\}$ denote the set of UEs associated with BS b at time t. Due to the load formulation and complex relation between UEA and BS operation, we decompose our problem into two subproblems, including UEA problem and resource allocation problem.

A. Distributed Load Balancing UE Association Policy

A major problem in the HetNet is to associate the UEs to the BSs. In conventional UEA technique, each UE is typically associated with the BS which offers the highest RSSI. Although this technique may lead to major drawbacks such as load imbalance and result in decreasing spectral efficiency. Therefore, techniques which capture BS's load can be more desirable [7]. On the other side, signals from differen BSs in a channel may interfere with each other. From the UE perspective, SINR metric is more important than RSSI metric. Because the radio link quality is governed by the dynamic CCI power and it is a major factor of performance degradation. In the following, given the set of BSs, we propose our UEA policy. We assume that the BSs broadcast their estimated load to the UEs through beacon signals [19]. Moreover, the UEs periodically assess their actual performance. Thus, if they are not satisfied with their current associations, they may decide to perform new associations. At each time t, the set of dropped UEs, the set of UEs belonging to BSs switched to OFF mode, and the set of new UEs joined to the HetNet should perform new association processes in order to assign to new BSs. We assume that each UE $k \in \mathcal{K}$ is associated with at most one BS at each time t, i.e. $\max \sum_{b \in \mathcal{B}} a_{b,k}^t \ = 1$. With assuming the resource to be fixed, at time t, UE k associates with BS $b_k^*(t)$ according to the following UEA policy

$$b_k^*(t) = \underset{b \in \mathcal{B}}{\operatorname{argmax}}\ 10\log_{10} \left(\gamma_{b,k}(t) (1 - \hat{L}_b(t))^{\eta_b} \right), \tag{9}$$

where $\eta_b \geq 0$ is a sensitivity parameter in order to control the effect of the BS's estimated load to the UEA rule. It balances the tradeoff between the probability of UE dropping and the link quality. With increasing η_b, the UEs are interested in to associate the lightly loaded BSs even the highly loaded BSs provide good SINR at the receiver of the UEs. $\hat{L}_b(t)$ indicates the estimated load of BS b at time *t* and is given by [19]

$$\hat{L}_b(t) = \left(1 - \left(\frac{1}{t} \right)^{\alpha} \right) \hat{L}_b(t-1) + \left(\frac{1}{t} \right)^{\alpha} L_b(t-1), \tag{10}$$

where $\alpha > 0$ denotes the learning rate exponent for the load estimation. Our proposed UEA policy implies that the UE makes decision on BS selection based on both offered SINR and the estimated load of BS.

From a practical perspective, the proposed policy requires the estimated load of BSs which are broadcasted in downlink. This information can be included in standards. For example, in IEEE 802.16m, some required parameters, such as cell load and cell type, for cell selection are considered [20].

B. Self-Organizing Resource Allocation

Now, we investigate the BS operation problem which comprises ON/OFF switching and channel assignment problem.

1) ON/OFF Switching Problem: With considering the apealing properties of BS load, for each BS $b \in \mathcal{B}$, we define a utility function which is a difference between a benefit function and a cost function [19]. The benefit function corresponds with the fraction of UEs associated with the BS. This term reflects how efficient the resource are utilized and/or a assessment from the income which may generate. The cost function captures the BS load and total power consumption. Therefore, we consider the utility function

$$\pi_b(t) = \underbrace{\omega_b^k \frac{|A_b^t|}{|\mathcal{K}|}}_{\text{Benefit}} - \underbrace{\left(\omega_b^l L_b(t) + \omega_b^p (P_b^{\mathrm{ON}}(t)\, \delta_{b \in \mathcal{B}_{\mathrm{ON}}} + P_b^{\mathrm{OFF}}(t)\, \delta_{b \in \mathcal{B}_{\mathrm{OFF}}}) \right)}_{\text{Cost}}, \tag{11}$$

where ω_b^k, ω_b^l and ω_b^p denote the weight parameters which indicate the impact of subscription benefit, load and energy on the utility function for each BS b, respectively. Depending on the network operators' preferences, with choosing the weight parameters, utility function π_b embodies different goals such as load balancing, improving the energy efficiency and increasing serving ratio (fraction of satisfied UEs associated with the BS). The objective is to maximize the total system utility

$$\begin{aligned} \max_{\{\boldsymbol{P}(t)\}} \quad & \sum_{t=1}^{T} \sum_{\forall b \in \mathcal{B}} \pi_b\left(t\right) \\ \text{subject to} \quad & P_b(t) \leq P_b^{\text{Max}}, \forall b \in \mathcal{B} \\ & q_b\left(t\right) \in \mathcal{Q}, \forall b \in \mathcal{B} \\ & a_{b,k}^{t} \in \{0,1\}, \forall b \in \mathcal{B}, \forall k \in \mathcal{K} \end{aligned} \tag{12}$$

where P_b^{Max} denotes the maximum transmit power of BS b. Now, we use a game theory framework, in which the BSs choose their power levels by seeking to optimize their own utility. We apply the noncooperative game $\mathcal{G} = \langle \mathcal{B}, \mathcal{S}_{b\in\mathcal{B}}, \pi_{b\in\mathcal{B}} \rangle$. Here, $\mathcal{B}$ represents the set of BSs as players, $\mathcal{S}_b$ is the strategy set of player b composed of transmit power $P_b \in [0, P_b^{\text{Max}}]$ and operation mode indicator $I_b \in \{0,1\}$, and π_b is the utility function of player b defined in (11). We use a no-regret learning approach described in [19] to solve the game and consequently obtain ϵ-coarse correlated equilibrium.

2) Channel Assignment Problem: Given the power selected in the ON/OFF switching scheme, each BS $b \in \mathcal{B}$ evaluates the average CCI power over each channel $q \in \mathcal{Q}$. Using the first order filtering with a forgetting factor λ, the average CCI power over channel q computed by BS b at time t is given by

$$\bar{I}_{b,q}(t) = (1-\lambda) I_{b,q}(t) + \lambda \, \bar{I}_{b,q}(t-1), \tag{13}$$

where $I_{b,q}(t)$ denotes instantaneous CCI power at BS b which is received over channel q at time t. Each BS $b \in \mathcal{B}$ has a CCI table which updates for all $q \in \mathcal{Q}$. Then, BS b selects the channel with minimum CCI power from the table [21].

IV. SIMULATION RESULTS

We consider a single hexagonal cell served by one MBS overlaid with the set of SBSs with 4 available channels, i.e. $|\mathcal{Q}| = 4$. Moreover, the BSs choose their channels according to the channel assignment algorithm in Section III. The communications are carried out in full buffer in accordance to the system parameters shown in Table I. For comparison purposes, we consider an additional scheme which keeps the BSs always ON and they transmit with their maximum power. It is referred to as "always ON", compared to ON/OFF switching approach. Furthermore, the proposed UEA policy is compared with the UEA scheme which is based on RSSI and estimated load [19], and it is referred to hereinafter as "baseline UEA". In this respect, in order to evaluate the performance of our proposed joint UEA and self-organizing resource allocation mechanism, which is referred to as "proposed UEA-ON/OFF switching", we consider the following benchmark references. In "baseline UEA-always ON", the UEA policy is based on baseline UEA scheme and the BSs transmit with their maximum power. In "baseline UEA-ON/OFF switching", the UEA policy is based on baseline UEA scheme and the BSs employ the ON/OFF switching scheme. In "proposed UEA-always ON", the UEs associate with the BSs according to our proposed UEA policy and the BSs transmit with their maximum power.

Fig. 2 shows average energy consumption per BS *vs* different number of UEs for 10 SBSs. We can observe that, for a given number of UEs, our proposed UEA-ON/OFF switching mechanism consumes less energy compared to the other approaches. However, the improvement over the approaches based on BSs always ON is more than baseline UEA-ON/OFF switching approach. The main reason is that baseline UEA-ON/OFF switching approach utilizes a sleep mode mechanism for unnecessary BSs whereas in the approaches based on BSs always ON, each BS transmits with its maximum power. For instance, when the number of UEs $= 10$, our proposed mechanism improves average energy consumption per BS about 3.4% and 26.4% over baseline UEA-ON/OFF switching approach and the approaches based on BSs always ON, respectively.

TABLE I
SYSTEM-LEVEL SIMULATION PARAMETERS

System Parameters		
Parameter		**Value**
Physical link type		Downlink
Carrier frequency/ Channel bandwidth		2 GHz/ 10 MHz
Noise power		-174 dBm/Hz
Traffic model		Full buffer
Mean packet arrival rate		1800 Kbps
Weights ω_b^n , ω_b^l, ω_b^p		1, 0.5, 0.5
Learning rate exponent α		0.9
BSs Parameters		
Parameter	**MBS**	**PBS**
Maximum power	46 dBm	30 dBm
Shadowing standard deviation	8 dB	10 dB
Cell radius	250 m	40 m
Distance-dependent path loss model	128.1+37.6$\log_{10}(d)$ d in Km	140.7+37.6$\log_{10}(d)$ d in Km
Minimum distance	MBS-SBS: 75m MBS-UE: 35m	SBS-SBS: 40m SBS-UE: 10m

Fig. 3 plots the average load per BS *vs* different number of SBSs, with 100 UEs. As the number of SBSs increases, the average load per BS decreases. We can observe that, our proposed UEA-ON/OFF switching mechanism outperforms the other algorithms in term of average load per BS through offloading UEs associated with highly loaded BSs to lightly loaded BSs. The fact is that our proposed UEA consider SINR which affects BS load, thus the impact of load on UEA increases. For instance, when the number of SBS $= 15$, the proposed mechanism improves the average load per BS by about 22% over the baseline UEA-always ON approach.

Fig. 4 compares the average load per BS *vs* different number of UEs for 10 SBSs. As the number of UEs increases, the average load per BS increases. It is shown that the proposed UEA-ON/OFF switching mechanism significantly outperforms the other approaches. For instance, when the number of UEs $= 110$, the average load per BS is improved by around 20% as compared to the baseline UEA-ON/OFF switching.

Fig. 5 illustrates the average utility per BS *vs* different number of UEs, with 10 SBSs. As the number of UEs increases, the energy consumption of BSs and the BS load increase. Therefore, the average utility per BS decreases. Since our proposed mechanism balances load and saves more energy than the other approaches, it improves the BS's utility. For instance, when the number of UEs $= 50$, our proposed mechanism improves the average utility per BS by about 32% and 35% over proposed UEA-always ON approach and baseline UEA-always ON approach, respectively.

V. CONCLUSION

In this paper, we have proposed a UEA policy based on

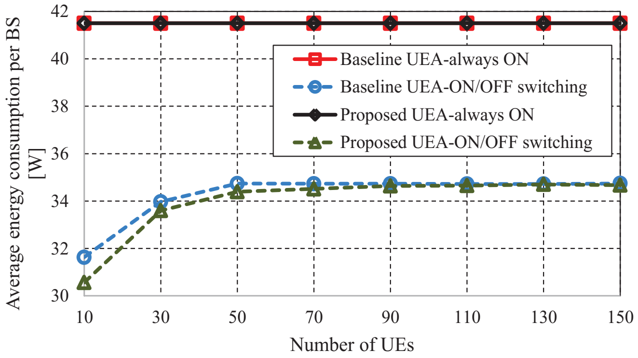

Fig. 2. Average energy consumption per BS *vs* the number of UEs, given 10 SBSs.

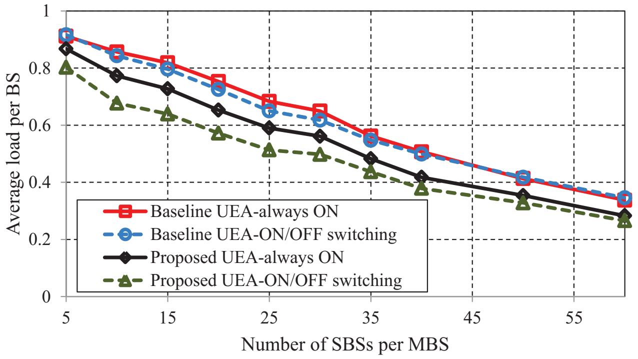

Fig. 3. Average load per BS *vs* the number of SBSs, given 100 UEs.

BS's estimated load and SINR.Then, we have combined this algorithm with a BSs ON/OFF switching scheme and an interference-aware channel allocation algorithm for jointly optimizing power and channel allocation. Our proposed joint UEA and resource allocation mechanism attempts to balance load among BSs and consequently can improve the spectral efficiency of the network. Furthermore, it is self-organizing and performs in a fully distributed manner. Simulation results have showed that, the proposed mechanism provides a better performance over the benchmark references and significantly outperforms them in terms of average energy consumption, average load, and average utility per BS.

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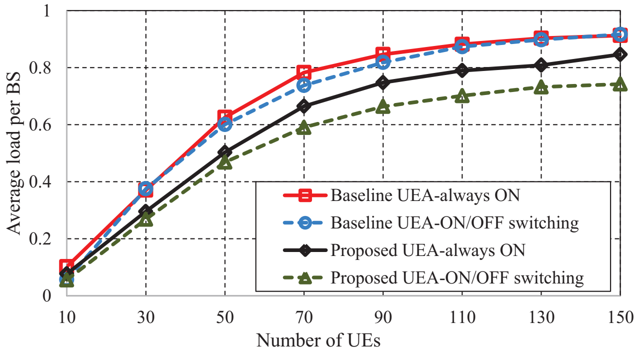

Fig. 4. Average load per BS *vs* the number of UEs, given 10 SBSs.

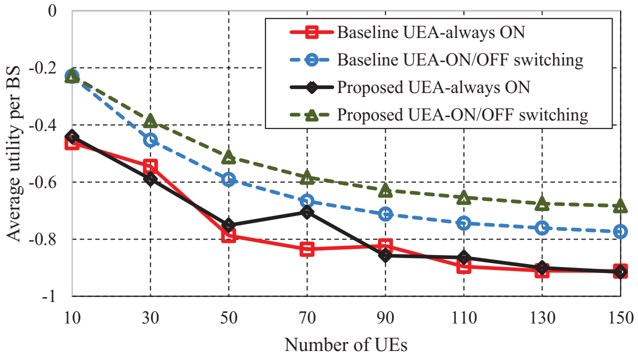

Fig. 5. Average utility per BS *vs* the number of UEs, given 10 SBSs.

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