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# Satisfaction Based Channel Allocation Scheme for Self-Organization in Heterogeneous Networks

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**Abstract**—The next-generation wireless networks are expected to become denser and more heterogeneous in order to boost the network capacity. However, densely deployed base stations (BSs) in heterogeneous networks (HetNets) can give rise to interference. On the other hand, a limited number of channels is allocated within the HetNets. Therefore, the efficient assignment of channels among BSs is considered to be an important issue. Furthermore, the density and heterogeneity of the networks motivate self-organizing resource management techniques. In this paper, we address the problem of channel allocation in HetNets, and propose a satisfaction based channel allocation algorithm. The problem is modeled as a game in satisfaction form, in which BSs act as the players with the constraint given by the loads at the BSs. The objective is to meet the data rate requirements of user equipments. In this regard, the BSs aim at seeking a satisfaction solution rather than the optimal one. In order to learn the satisfaction equilibrium, a fully distributed algorithm based on the individual utility is applied. Simulation results show that the proposed approach can increase the average BS's throughput compared to the benchmark algorithms.

**Index Terms**—Heterogeneous Networks; Game Theory; Satisfaction Algorithm; Channel Allocation.

## I. INTRODUCTION

With the increasing demand for higher rate data services, the deployment of heterogeneous networks (HetNets) are envisioned to enable next-generation wireless networks [1]. In HetNets, macro cell base stations (MBSs) and small cell base stations (SBSs) are expected to coexist in a complex manner [2]. However, the dense deployment of HetNets may degrade the service quality due to co-channel interference. Therefore, there is a need for self-organizing solutions, in which BSs can manage resources, and adapt to the changes in the network's conditions with minimal human intervention. In this regard, an effective and flexible channel allocation algorithm can help to improve the network's throughput by utilizing the appropriate channels for base stations (BSs).

Channel allocation schemes can be categorized as centralized approaches and distributed approaches [3]–[5]. In the centralized approach, a controller entity optimizes the channel allocation to meet the quality of service (QoS) requirements. However, this may increase implementation complexity, especially as the network's size increases. In a distributed

approach, each BS independently selects its channel based on the network's conditions. Another classification can be found as: fixed, dynamic and hybrid channel allocation [6]–[9]. In a fixed channel allocation scheme, the available channels are permanently assigned to cells based on the predetermined traffic demand [9]. A dynamic channel allocation scheme dynamically assigns the channels to cells according to the network's conditions. In a hybrid channel assignment, the set of channels is divided into two disjoint sets including some channels that are allocated to cells using a fixed channel allocation scheme and other channels allocated using a dynamic channel allocation scheme.

Several works have studied the channel allocation problem in wireless networks. In [10], a frequency allocation approach is proposed that guarantees a minimum average throughput to user equipments (UEs). Moreover, it requires little coordination among BSs. To minimize the cross-tier interference, a distributed spectrum allocation algorithm for two-tier networks is developed in [11]. The proposed approach is optimal in terms of area spectral efficiency. The authors in [12] proposed an interference-aware channel segregation algorithm. In this approach, each BS calculates its co-channel interference over each channel, and selects the channel with the lowest interference. In [13], a two-stage dynamic channel assignment approach for the downlink of dense femtocell networks is proposed. This approach utilizes a graph coloring algorithm to group femtocell UEs. A channel assignment method based on genetic algorithms is presented in [14], where two algorithms, general purpose simple genetic algorithm and the local search based hybrid genetic algorithm, are used.

In the context of wireless networks, the framework of noncooperative game theory can be used as a tool for investigating the behaviors of decision makers/autonomous agents (as the players) and modeling competitions among them in the networks. In a game in normal form, each player aims at maximizing its utility function in a selfish way. In [15], the problem of channel assignment and UE association in dense IEEE 802.11 wireless network is modeled as a non-cooperative game. The solution of the game converges to a Nash equilibrium. However, most widely used applications in wireless networks do not require the players to optimize their individual performances and attain the highest achievable QoS level. Therefore, each player is interested in the satisfaction of some individual constraints, instead of optimization [16].

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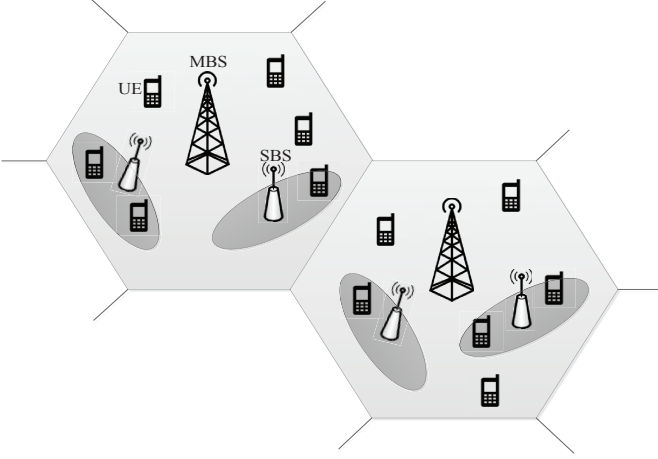


Figure 1. An illustration of a two-tier HetNet.

In this regard, a new solution concept known as *satisfaction equilibrium* is presented in [17], [18]. In a game in satisfaction form, if a player is satisfied, it has no interest in changing its strategy [19], [20]. Therefore, once all players are simultaneously satisfied, an equilibrium is obtained, which is referred to as satisfaction equilibrium.

In this paper, we propose a self-organizing mechanism for channel allocation problem in HetNets, in which the problem is formulated as a noncooperative game in satisfaction form. We consider a utility function as a function of BS's throughput. To learn an equilibrium, a fully distributed learning algorithm is applied. In the algorithm, the probability distribution assigned to the strategies of a player is updated according to the observed individual utility. This algorithm is modified version of the algorithm presented in [21]. In this regard, if the player is not satisfied with its obtained utility, it selects its strategy according to the probability distribution; otherwise, it has no inclination to change it. However, in the realm of wireless communications, all players might not always be satisfied simultaneously. To overcome this constraint, we decrease the satisfaction threshold for unsatisfied players after a certain time period.

The rest of this paper is organized as follows. Section II describes the system model and the assumptions. In Section III, the idea of satisfaction equilibrium is described, and the proposed channel allocation algorithm is presented. In Section IV, we evaluate the performance of the proposed scheme. Finally, Section V concludes the paper.

*Notations:* The regular and boldface symbols refer to scalars and matrices, respectively. For any finite set  $\mathcal{A}$ , the cardinality of set  $\mathcal{A}$  is denoted by  $|\mathcal{A}|$ .  $\mathbf{X}^T$  denotes the transpose of matrix  $\mathbf{X}$ . The function  $\mathbb{1}_\phi$  denotes the indicator function which equals 1 if event  $\phi$  is true and 0, otherwise.

## II. SYSTEM MODEL

We consider the downlink of a two-tier HetNet with the set of BSs  $\mathcal{B}$  including MBSs and SBSs as depicted in Fig. 1. The

set of UEs is denoted by  $\mathcal{K}$ . Assume that the total bandwidth  $\omega$  is divided in  $|\mathcal{N}|$  orthogonal channels with bandwidth  $\omega/|\mathcal{N}|$ , where  $\mathcal{N}$  is the set of channels. We adopt a load-coupled model to account for the effect of the load conditions over interference [22]. The load of a BS is referred to the fraction of resources that are utilized in the BS. Let  $p_b(t)$  and  $g_{b,k}(t)$  be the transmit power of BS  $b$  and the channel gain from BS  $b$  to UE  $k$  at time  $t$ , respectively. Thus, the signal to interference plus noise ratio (SINR) experienced by UE  $k$  associated with BS  $b$  can be expressed as [23]:

$$\gamma_{b,k}(t) = \frac{p_b(t)g_{b,k}(t)}{\sum_{b' \in \mathcal{B} \setminus b} p_{b'}(t)g_{b',k}(t)\rho_{b'}(t)\mathbb{1}_{\{n_b(t)=n_{b'}(t)\}} + \sigma^2}, \quad (1)$$

where  $n_b(t)$  and  $\sigma^2$  denote the channel over which BS  $b$  is transmitting at time  $t$  and the additive white Gaussian noise (AWGN) power, respectively. Here,  $\rho_b(t)$  is the load of BS  $b$  at time  $t$ . Hence, the achievable rate of UE  $k$  from BS  $b$  using Shannon's capacity formula is given by:

$$R_{b,k}(t) = \frac{\omega}{|\mathcal{N}|} \log_2(1 + \gamma_{b,k}(t)). \quad (2)$$

We consider that each UE  $k \in \mathcal{K}$  is guaranteed to achieve the bit rate target  $\vartheta_k$ . The UE's utilization  $\frac{\vartheta_k}{R_{b,k}(t)}$  is defined as the fraction of the resources at BS  $b$  to serve UE  $k$ . Thus, the load of BS  $b$  can be expressed as [24]:

$$\begin{aligned} \rho_b(t) &= \sum_{k \in \mathcal{K}_b} \frac{\vartheta_k}{R_{b,k}(t)} = \\ &= \sum_{k \in \mathcal{K}_b} \frac{\vartheta_k}{\frac{\omega}{|\mathcal{N}|} \log_2(1 + \frac{p_b(t)g_{b,k}(t)}{\sum_{b' \in \mathcal{B} \setminus b} p_{b'}(t)g_{b',k}(t)\rho_{b'}(t)\mathbb{1}_{\{n_b(t)=n_{b'}(t)\}} + \sigma^2})} \\ &\triangleq h_b(\boldsymbol{\rho}), \end{aligned} \quad (3)$$

where  $\mathcal{K}_b$  is the set of UEs associated with BS  $b$ . Let  $\boldsymbol{\rho} = (\rho_1, \dots, \rho_{|\mathcal{B}|})^T$  be the BS load vector. Eq. (3) represents the load coupling relation among BSs, in which the loads of other BSs have an impact on the load of BS  $b$ . The function  $h_b(\cdot)$  is used to indicate this relation. In vector form, the non-linear load coupling equation is obtained as follows [24]:

$$\boldsymbol{\rho} = \mathbf{h}(\boldsymbol{\rho}), \quad (4)$$

where  $\mathbf{h}(\boldsymbol{\rho}) = (h_1(\boldsymbol{\rho}), \dots, h_{|\mathcal{B}|}(\boldsymbol{\rho}))^T$  is the vector of load functions. To solve (4), a fixed-point iteration algorithm is applied [24]. Since the network has the limited resources, the BS's load cannot exceed one. If the load of a BS exceeds this value, it will drop some UEs (referred to as UEs in outage), and decrease their rates according to the UE's utilization [25].

For UE-BS association, at each time instant  $t$ , each UE  $k \in \mathcal{K}$  is served by BS  $b(k, t)$  as follows [20]:

$$b(k, t) = \operatorname{argmax}_{b \in \mathcal{B}} \{p_b(t)g_{b,k}(t)(1 - \hat{\rho}_b(t))\}, \quad (5)$$

where  $\hat{\rho}_b(t)$  denotes the estimated load of BS  $b$  at time  $t$ , which is advertised by BS  $b$  through a broadcast control message. The estimated load  $\hat{\rho}_b(t)$  is calculated as follows [20]:

$$\hat{\rho}_b(t) = \hat{\rho}_b(t-1) + \tau(t) \left( \rho_b(t-1) - \hat{\rho}_b(t-1) \right), \quad (6)$$

where  $\tau(t)$  is the learning rate for the load estimation, in which it follows the format of  $1/t^\beta$  with exponent  $\beta < 1$ .

### III. SATISFACTION BASED CHANNEL ALLOCATION

In this section, we first formulate the channel allocation problem in the HetNet as a noncooperative game in satisfaction form. To solve the game, a distributed satisfaction algorithm is applied.

#### A. Problem Formulation

The optimization problem aims at achieving a target required service rate  $\vartheta_k$  for each UE  $k \in \mathcal{K}$ . For each BS  $b \in \mathcal{B}$ , we define a utility function as follows:

$$u_b(t) = \begin{cases} \frac{C_b(t)}{\sum_{k \in \mathcal{K}_b} \vartheta_k}, & \mathcal{K}_b \neq \emptyset \\ 0, & \text{otherwise,} \end{cases} \quad (7)$$

where  $C_b(t)$  denotes the throughput of BS  $b$  at time  $t$ . The following optimization problem formulation can be defined as follows:

$$\max_{\mathbf{n}(t) = (n_1(t), \dots, n_{|\mathcal{B}|}(t))} \sum_{b \in \mathcal{B}} u_b(t) \quad (8a)$$

$$\text{subject to} \quad \rho_b(t) = h_b(\boldsymbol{\rho}), \quad \forall b \in \mathcal{B} \quad (8b)$$

$$0 \leq \rho_b(t) \leq 1, \quad \forall b \in \mathcal{B}. \quad (8c)$$

For the optimization problem (8), the constraints in (8b)- (8c) correspond to the definition of load.

The channel allocation problem can be formulated as a non-cooperative game in satisfaction form. The game in satisfaction form is described by the following triplet:

$$\mathcal{G}_{\text{SF}} = \langle \mathcal{B}, \{\mathcal{S}_b\}_{b \in \mathcal{B}}, \{f_b\}_{b \in \mathcal{B}} \rangle, \quad (9)$$

where the set of BSs,  $\mathcal{B}$ , is considered as the players. The strategy set of player  $b$ ,  $\mathcal{S}_b$ , is the set of channels  $\mathcal{N}$ . The correspondence  $f_b(\mathbf{s}_{-b}) : \mathcal{S}_{-b} \rightarrow 2^{\mathcal{S}_b}$  determines the set of strategies that satisfy the constraint of player  $b$  given the strategies of all other players  $\mathbf{s}_{-b}$ , where  $\mathbf{s}_{-b} = (s_1, \dots, s_{b-1}, s_{b+1}, \dots, s_{|\mathcal{B}|})$  and  $\mathcal{S}_{-b} = \mathcal{S}_1 \times \dots \times \mathcal{S}_{b-1} \times \mathcal{S}_{b+1} \times \dots \times \mathcal{S}_{|\mathcal{B}|}$ . Note that each player in a game in satisfaction form can select a strategy independently of all other players. The dependence on the other players' strategies is considered for determining the satisfaction of a player [26]. For each player  $b \in \mathcal{B}$ , an individual player satisfaction indicator  $I_b(t)$  can be defined using the binary representation as follows:

$$I_b(t) = \begin{cases} 1, & \text{if } s_b(t) \in f_b(\mathbf{s}_{-b}) \\ 0, & \text{otherwise.} \end{cases} \quad (10)$$

Here,  $s_b(t)$  represents the strategy of player  $b$  at time  $t$  (i.e. the selected channel  $n_b(t)$ ). Let the correspondence  $f_b$  be defined as follows:

$$f_b(\mathbf{s}_{-b}) = \{s_b \in \mathcal{S}_b : u_b(t) \geq \Gamma_b\}, \quad (11)$$

where  $\Gamma_b$  denotes the satisfaction threshold, meaning that player  $b$  is satisfied if its utility is at least  $\Gamma_b$ . An outcome of the game in satisfaction form is called *satisfaction equilibrium*. For each player  $b \in \mathcal{B}$ , if  $f_b(\mathbf{s}_{-b})$  is not empty, a satisfaction equilibrium is met. (i.e. all players simultaneously satisfy their constraints.)

*Definition 1 (Satisfaction Equilibrium):* A strategy profile  $\mathbf{s}^* = (s_1^*, \dots, s_{|\mathcal{B}|}^*)$  is called a satisfaction equilibrium for the game  $\mathcal{G}_{\text{SF}}$  if  $\forall b \in \mathcal{B}$

$$s_b^* \in f_b(\mathbf{s}_{-b}^*). \quad (12)$$

A satisfaction equilibrium is a solution of the channel allocation problem in satisfaction form. However, a satisfaction equilibrium may not always exist for a given satisfaction threshold. Hence, after each time period  $T$ , an unsatisfied player  $b$  can reduce its satisfaction threshold by factor  $\alpha_b \cdot \Gamma_b$ . Here,  $T$  should be large enough such that the player is able to try almost all strategies in order to satisfy. Therefore, if the player be unsatisfied in  $i$  time periods, it redefines its threshold as  $\Gamma_b \cdot (1 - i \cdot \alpha_b)$ .

#### B. Learning Satisfaction Equilibria

In this subsection, a satisfaction equilibrium search algorithm based on the algorithm described in [18] is applied to achieve a satisfaction equilibrium. This algorithm is executed in a fully distributed manner. Thus, it is suitable for scenarios having a dense deployment of BSs. We assume that each player knows its set of strategies and latest selected strategy. Furthermore, the player is able to periodically observe its achieved utility and thus, it can also observe whether it is satisfied or not.

If a player achieves its constraint, it has no incentive to change its strategy. Meanwhile, the unsatisfied players select their strategies based on their probability distributions. Let  $\boldsymbol{\pi}_b(t) = (\pi_{b,1}(t), \dots, \pi_{b,|\mathcal{S}_b|}(t))$  be the probability distribution assigned to the strategies of player  $b$  at time  $t$ , where  $\pi_{b,i}(t)$  is the probability assigned to the strategy  $s_{b,i} \in \mathcal{S}_b$  at time  $t$ . The satisfaction equilibrium search algorithm is carried out as follows:

- 1) At time instant  $t = 0$ , each player  $b \in \mathcal{B}$  chooses its strategy based on the uniform distribution (i.e.  $\pi_{b,i}(0) = \frac{1}{|\mathcal{S}_b|}, \forall s_{b,i} \in \mathcal{S}_b$ ).
- 2) For each time instant  $t$ , each player  $b \in \mathcal{B}$  observes its utility, and calculates its individual satisfaction indicator  $I_b(t)$ . If the player is satisfied (i.e.  $I_b(t) = 1$ ), it keeps playing the same strategy at time  $t+1$ . But if player  $b$  is unsatisfied (i.e.  $I_b(t) = 0$ ), it selects its strategy  $s_b(t+1)$  according to the probability distribution  $\boldsymbol{\pi}_b(t+1)$ . Therefore, it updates its strategy as follows [18]:

**Algorithm 1** : Satisfaction based channel allocation algorithm

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1: Require: At each time instant  $t > 0, \forall b \in \mathcal{B}: I_b(t)$ .
   Initialization ( $t \leftarrow 0$ ):
2: for each  $b \in \mathcal{B}$  do
3:   for each  $s_{b,i} \in \mathcal{S}_b$  do
4:      $\pi_{b,i}(0) = \frac{1}{|\mathcal{S}_b|}$ ,
5:   end for
6:   Select a strategy  $s_b(0) \sim \pi_b(0)$ ,
7:   Calculate  $u_b(0)$  and  $I_b(0)$ , according to (7) and (10),
8:   Update  $\pi_b(1)$ , according to (14),
9: end for
10: for each  $t > 0$  do
11:   for each  $b \in \mathcal{B}$  do
12:     Select a strategy  $s_b(t)$  according to (13),
13:     Calculate  $u_b(t)$  and  $I_b(t)$ , according to (7) and (10),
14:     for each  $s_{b,i} \in \mathcal{S}_b$  do
15:       Update  $\pi_{b,i}(t+1)$ , according to (14),
16:     end for
17:   end for
18: end for

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$$s_b(t+1) = \begin{cases} s_b(t), & \text{if } I_b(t) = 1 \\ \sim \pi_b(t+1), & \text{if } I_b(t) = 0, \end{cases} \quad (13)$$

where  $\sim \pi_b(t+1)$  means according to the probability distribution  $\pi_b(t+1)$ .

- 3) Each player  $b \in \mathcal{B}$  updates the probability assigned to each strategy  $s_{b,i} \in \mathcal{S}_b$  as follows:

$$\pi_{b,i}(t+1) = \begin{cases} \pi_{b,i}(t), & \text{if } I_b(t) = 1 \\ d_b(\pi_{b,i}(t)), & \text{if } I_b(t) = 0, \end{cases} \quad (14)$$

with

$$d_b(\pi_{b,i}(t)) = \pi_{b,i}(t) + \mu_b(t)r_b(t)\left(\mathbb{1}_{\{s_b(t)=s_{b,i}\}} - \pi_{b,i}(t)\right), \quad (15)$$

where  $\mu_b(t) = \frac{1}{t+1}$  is the learning rate of player  $b$ . The parameter  $r_b(t)$  is computed as follows [18]:

$$r_b(t) = \frac{1 + u_b(t) - \Gamma_b}{2}. \quad (16)$$

Note that, in order to assign the probabilities to the strategies, each player only requires the knowledge of its observed utility.

- 4) To select the strategy  $s_b(t)$  based on the probability distribution  $\pi_b(t)$ , player  $b$  uses a mapping function  $M: \pi_b(t) \mapsto s_{b,i} \in \mathcal{S}_b$ .

The pseudocode for the proposed satisfaction channel allocation algorithm is presented in Algorithm 1.

**Theorem 1:** The proposed channel allocation algorithm converges to an equilibrium of the game  $\mathcal{G}_{\text{SF}}$  in finite time.

*Proof.* Follows from [20, Theorem 2]. ■

Table I  
SYSTEM-LEVEL SIMULATION PARAMETERS

System Parameters		
Parameter	Value	
Carrier frequency/ Channel bandwidth	2 GHz/ 10 MHz	
Noise power spectral density	-174 dBm/Hz	
$\vartheta_k$	1800 Kbps	
Learning rate exponent for $\tau$ ( $\beta$ )	0.9	
$T$	100	
$\Gamma_b$	1	
$\alpha_b$	0.1	
BS Parameters		
Parameter	MBS	SBS
Transmit power	46 dBm	30 dBm
$ \mathcal{S}_b $	4	4
Radius cell	250 m	40 m
Distance-dependent path loss model ( $d$ in Km)	$128.1+37.6 \log_{10}(d)$	$140.7+36.7 \log_{10}(d)$
Minimum distance	MBS-SBS: 75 m MBS-UE: 35 m	SBS-SBS: 40 m SBS-UE: 10 m

#### IV. SIMULATION RESULTS

We consider a HetNet with a MBS located in the center of a hexagonal layout. The SBSs and the UEs are uniformly distributed in the coverage area of the MBS, with some constraints on the minimum distance between various BSs and UEs according to [27]. The simulation parameters are summarized in Table I.

To evaluate the performance of the proposed self-organizing solution, we compare the satisfaction approach with the following algorithms:

- *Random:* each BS selects its channel randomly from a uniform distribution (i.e.  $\pi_{b,i}(t) = \frac{1}{|\mathcal{N}|}$  for  $\forall b \in \mathcal{B}$  and  $\forall s_{b,i} \in \mathcal{S}_b$ ).
- *Baseline- $\omega$ :* all BSs transmit over a channel with bandwidth  $\omega$ .
- *Baseline- $\omega/|\mathcal{N}|$ :* all BSs transmit over a channel with bandwidth  $\omega/|\mathcal{N}|$ .

Fig. 2 shows the average rate per UE as the number of UEs varies for a network with 5 SBSs. The proposed satisfaction approach yields an improvement in the UE rates when compared to the benchmark approaches, and achieves almost thrice the rates compared to the baseline approach with  $\omega/|\mathcal{N}|$ . For a network with 130 UEs, the improvement of rate per UE in the satisfaction approach compared to the random scheme and baseline- $\omega$  is about 35% and 30%, respectively. Moreover, as the number of UEs increases, a drop in the rate per UE can be seen for all approaches. The reason for this is that with an increasing number of UEs in the network, the loads of BSs increase and thus, the interference increases. More interference decreases the SINR, resulting in a lower rate for UEs.

Fig. 3 illustrates the average rate per UE for different number of SBSs for a network with 100 UEs. We can observe that with increasing the number of SBSs, the average rate per UE increases. Furthermore, the satisfaction approach yields a

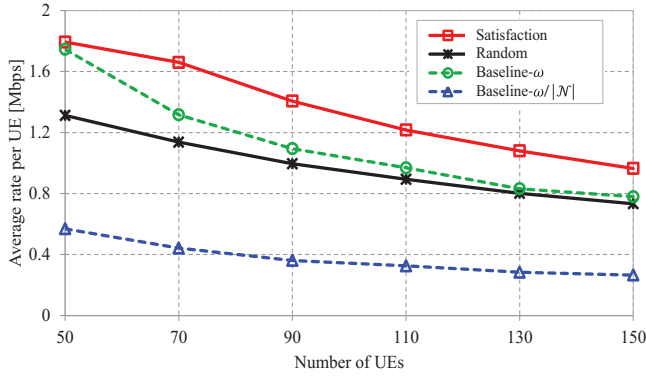


Figure 2. Average rate per UE versus the number of UEs, given 5 SBSs.

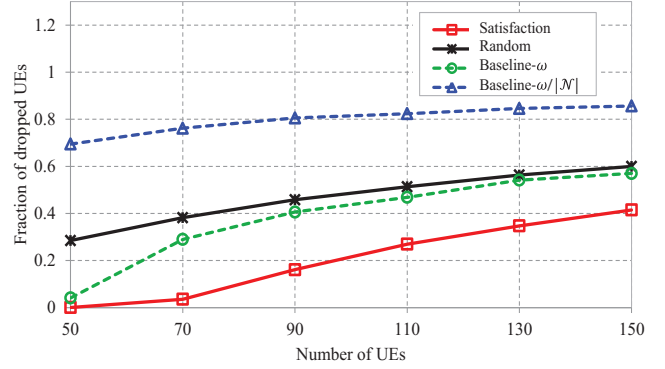


Figure 4. Fraction of dropped UEs versus the number of UEs, given 5 SBSs.

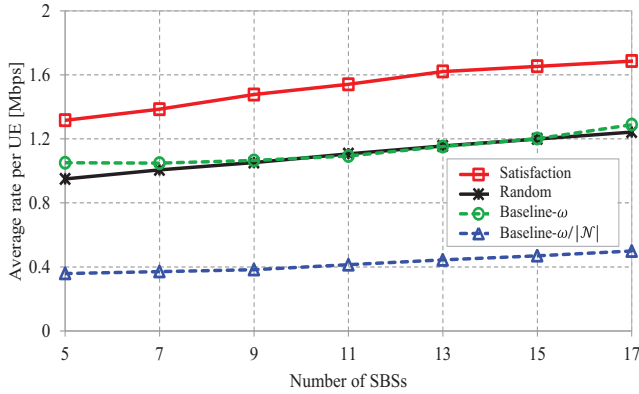


Figure 3. Average rate per UE versus the number of SBSs, given 100 UEs.

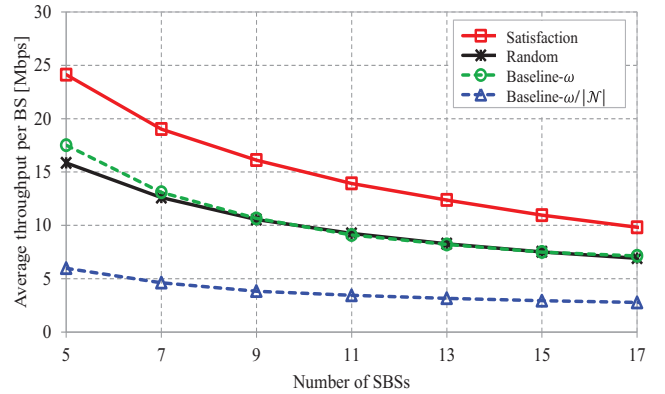


Figure 5. Average throughput per BS versus the number of SBSs, given 100 UEs.

significant improvement in UE's rate compared to the benchmark algorithms. For instance, the proposed scheme achieves about 41% and 39% improvement in terms of UE's rate, respectively, compared to baseline- $\omega$  and random algorithm, for a network with 11 SBSs.

In Fig. 4, we depict the outage probability as the fraction of UEs whose arrivals are dropped due to the overload of BSs for different number of UEs, for a network with 5 SBSs. The proposed scheme ensures a lower dropped UEs; thus, a lower number of UEs suffer from outage. Moreover, as the number of UEs in the network increases, the number of dropped UEs increases. This is mainly due to the fact that, the loads of BSs increase and more BSs are overloaded; thus, they need to limit their loads to value one. From Fig. 4, we can observe that the satisfaction approach yields about 91%, 88%, and 95% reductions in dropped UEs compared to the random scheme, baseline- $\omega$  approach and baseline- $\omega/|\mathcal{N}|$  approach, respectively, for a network with 70 UEs.

In Fig. 5, we illustrate the average throughput per BS as the number of SBSs varies, for a network with 100 UEs. In the proposed satisfaction approach, the BSs select the better downlink channel compared to the benchmark algorithm, resulting in achieving a higher throughput per BS. For instance, the satisfaction method improves the throughput by about 51%, 50%, 291% compared to baseline- $\omega$  approach, random

algorithm, and baseline- $\omega/|\mathcal{N}|$ , respectively, for a network with 13 SBSs.

In Fig. 6, we further assess the performance of the satisfaction approach in terms of BS's throughput, under different number of UEs for 5 SBSs in the network. In this figure, we observe that as the number of UEs increases, the average throughput per BS increases. Moreover, the satisfaction approach yields a higher throughput compared to the benchmark algorithms. Fig. 6 shows the proposed approach improves the average throughput up to 3 times compared to the baseline- $\omega/|\mathcal{N}|$  algorithm. Moreover, the satisfaction approach yields, respectively, up to about 41% and 55% of throughput improvement, relative to the baseline- $\omega$  and random algorithm for a network with 90 UEs.

In Fig. 7, we show the average load per BS as the number of SBSs varies for 100 UEs. For the number of SBSs more than 9, the proposed satisfaction approach decreases average load per BS compared to the random algorithm. This result demonstrates that the proposed approach can balance the load among the BSs for dense scenarios. Furthermore, as the network becomes denser (i.e. the number of SBSs increases), the average load per BS decreases. For a network with 17 SBSs, the satisfaction approach reduces the average load per BS about 15%, 26%, and 37% compared to the random algorithm, baseline- $\omega$ , and baseline- $\omega/|\mathcal{N}|$  algorithm, respectively.

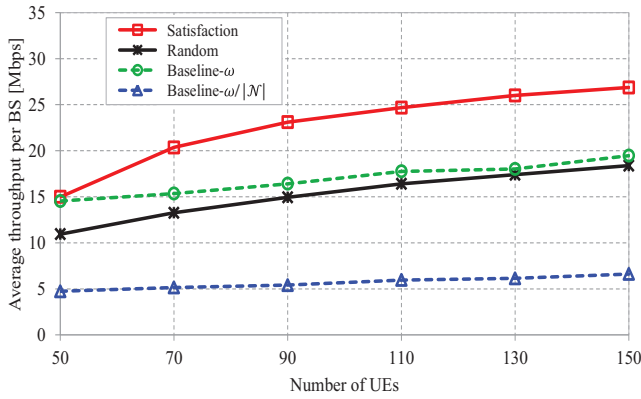


Figure 6. Average throughput per BS versus the number of UEs, given 5 SBSs.

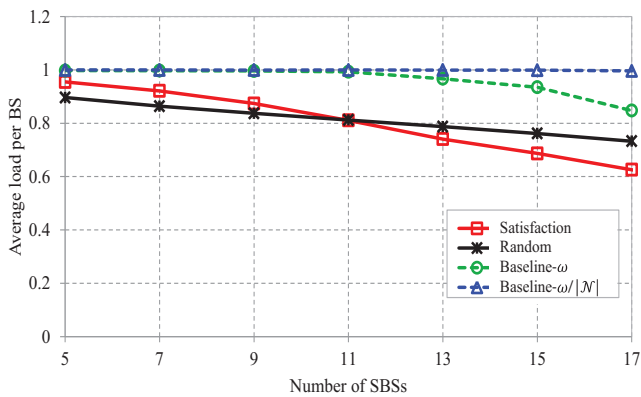


Figure 7. Average load per BS versus the number of SBSs, given 100 UEs.

## V. CONCLUSION

In this paper, a satisfaction based channel allocation algorithm for self-organizing HetNets, has been proposed. The problem is modeled as a noncooperative game in satisfaction form. To solve the game, a learning algorithm based on the observed utility is applied. In this approach, if a BS is satisfied with its obtained utility, it has no interest to change its channel. Furthermore, the satisfaction equilibrium search algorithm can be executed in a flexible and distributed manner. Simulation results have shown that the proposed approach can significantly improve the UE's rate, and decrease the number of dropped UEs in the network, compared to the benchmark algorithms.

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