SDN-Based Hierarchical Agglomerative Clustering Algorithm for Interference Mitigation in Ultra-Dense Small Cell Networks

Guang Yang, Yewen Cao, Amir Esmailpour, and Deqiang Wang

Ultra-dense small cell networks (UD-SCNs) have been identified as a promising scheme for next-generation wireless networks capable of meeting the ever-increasing demand for higher transmission rates and better quality of service. However, UD-SCNs will inevitably suffer from severe interference among the small cell base stations, which will lower their spectral efficiency. In this paper, we propose a software-defined networking (SDN)-based hierarchical agglomerative clustering (SDN-HAC) framework, which leverages SDN to centrally control all sub-channels in the network, and decides on cluster merging using a similarity criterion based on a suitability function. We evaluate the proposed algorithm through simulation. The obtained results show that the proposed algorithm performs well and improves system payoff by 18.19% and 436.34% when compared with the traditional network architecture algorithms and non-cooperative scenarios, respectively.

Keywords: Hierarchical agglomerative clustering, Interference mitigation, Software-defined networking, Ultra-dense small cell networks.

I. Introduction

In the past few years, we have witnessed a rapid growth in the popularity of portable devices such as laptops, smart phones, and tablets. This phenomenon has created a growing demand for wireless traffic. To boost spectral efficiency and obtain extra transmission bandwidth, some technologies have been proposed; that is the case, for example, of massive multiple-input multiple-output [1] and millimeter-wave mobile communications [2]. Additionally, the concept of small cell has been proposed as a means to reduce energy consumption, meet the seamless coverage requirements, and improve network throughput in cellular networks [3]. However, given that the above-mentioned technologies will not be sufficient to handle the rapidly increasing data traffic requirements or the demands for better coverage and more efficient energy consumption, ultra-dense small cell networks (UD-SCN) have been considered as a potential candidate technology for the next-generation networks and have been attracting much attention in recent years [4]–[7].

Nevertheless, the research on UD-SCNs is still at its early stages, and is now facing significant spectrum efficiency issues, especially in dense deployment areas such as shopping malls and apartment blocks, where neighboring small cell base stations (SBSs) interfere with each other while striving for spectrum usage. The interference between SBSs—which is called co-tier interference—can have a negative impact on the users' experience. Therefore, interference mitigation is a major research challenge that has been widely studied in the literature. Within the scope of non-cooperative methods—in which the SBSs operate without cooperation—the currently existing research areas include interference

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alignment [8], fractional frequency reuse [9], the introduction of cognitive base-stations [10], interference coordination [11], interference cancelation [12], [13], power minimization for interference mitigation [14], self-organized spectrum access in small cell networks (SCNs) [15], resource optimization based on interference management [16], and so on. In the past few years, some studies focusing on cooperation schemes between SBSs have also been proposed. To maximize the energy efficiency of SCNs, the authors in [17] proposed a cluster-based dynamic mechanism to locally integrate coupled SBSs into clusters. The authors in [18] presented a coalition game-based resource allocation approach to enable self-healing and cell outage compensation in SCNs. The authors in [19] formulated SBSs' cooperation as a coalition formation game with overlapping coalitions. The authors in [20] designed a cluster-based resource allocation scheme considering the sub-channel and power assignment problems of downlink transmission in UD-SCNs. To improve the spectral efficiency of UD-SCNs, the authors in [21] introduced a bargaining cooperative game algorithm to investigate potential cooperation gains. The authors in [22] proposed a novel cooperative approach among adjacent small cells, which was formulated as a coalitional structure generation with characteristic forms. This method is particularly applicable to massive small cell deployment scenarios.

Despite the many existing research approaches to interference mitigation, most solutions are not sufficiently flexible to adapt to the nature of UD-SCNs. In addition, the existing schemes are generally proprietary, which makes it difficult to fully exert their functionality to improve network performance. More recently, software-defined networking (SDN) has emerged as a flexible and efficient alternative for data network management by decoupling the control and data planes [23]–[26]. The SDN controller is software-based, and the entire network operation is derived from it. Compared with the conventional distributed network control mode, the centralized mode is potentially promising because controlling the network behavior becomes easier in this mode. Hence, applying SDN principles to traditional radio access networks is a logical step [27], [28]. Using an SDN controller will improve the cooperative efficiency between base stations, because it will facilitate decreasing the exchange of information between them. Building on this latest development, we propose a hierarchical agglomerative clustering algorithm for interference mitigation in UD-SCNs using SDN. First, the goal of adopting the hierarchical agglomerative clustering algorithm is to partition all members (SBSs) into groups or clusters, based on a similarity criterion. An appropriate similarity criterion—complemented by a suitability function—is therefore developed, which is capable of grouping members into an effective model. Second, we leverage the idea of SDN and propose an interference mitigation approach that is implemented by flexibly and effectively assigning sub-channels. This approach runs in the SDN controller, which differs from a distributed controller. Third, we show via simulations that the proposed SDN-HAC algorithm provides a higher transmission rate than the traditional network architecture algorithms in both cooperative and non-cooperative cases.

The remainder of this paper is organized as follows. Section II presents a tractable model for the SDN-based SCN considered in this paper. In Section III, we detail the proposed SDN-based hierarchical agglomerative clustering (SDN-HAC) algorithm. Section IV presents some simulation results and the respective analysis. Section V concludes the paper.

II. System Model

Our work is based on a software-defined SCN. We assume the existence of a large SCN consisting of F SBSs controlled by an SDN controller. A simple example of a software-defined SCN composed of a large amount of SBSs is shown in Fig. 1. All SBSs are connected to the SDN controller by ideal backhauls, which decouple the control plane from the data plane. Additionally, using the OpenFlow SDN standard we can monitor the networking information and can subsequently decide which configuration is best applied to the entire network. By means of these backhauls, the SBSs can transmit their status information to the SDN controller, which can then send control information to the SBSs. In this way, the cooperation between SBSs can be managed by the SDN control plane. Here, we assume that the access for all SBSs is of the closed-access type. $\mathbf{F} = \{1, \ldots, F\}$ indicates the number of SBSs in the network and collects all SBSs' indices. Each SBS $f \in \mathbf{F}$ serves U_f small-cell user equipment (SUE) units and $\mathbf{U} = \{1, \ldots, U\}$ collects all SUE units served by SBSs. The downlink transmission of the SBSs uses an orthogonal frequency division multiple access (OFDMA) scheme, which means that there exists no intra-cell interference and the SUE only suffers co-tier interference from other SBSs.

It should be noted that, in a hyper-dense deployment of SBSs, co-tier interference is an extremely serious problem, which can greatly decrease system performance [19], [29].

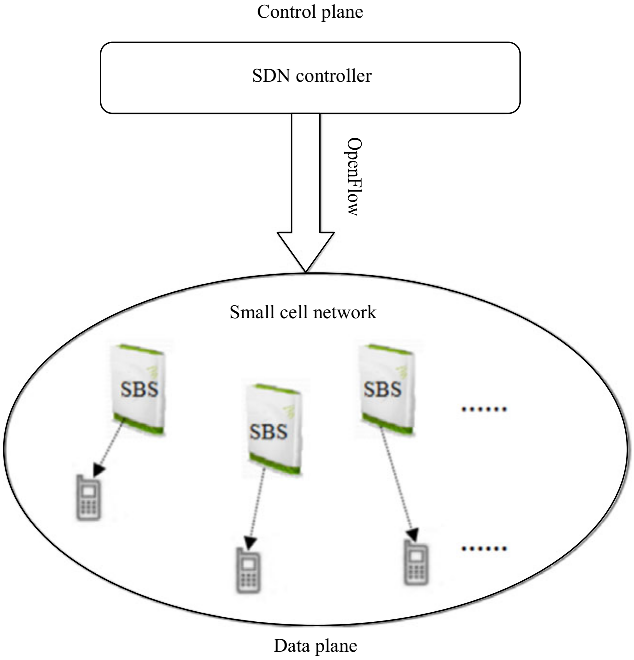

Fig. 1. Simple example of an SDN-based small cell network.

However, in this work, we assume that all SBSs are located in hotspot, indoor, large areas, with no walls between each SBS and its corresponding SUE, and that there are walls between different SBSs. Meanwhile, since the macro cell is deployed outdoors, there are walls between the macro cell and the SBSs or their SUE. Considering the wall loss and the long distance between the macro cell and the SUE, the cross-tier interference is much weaker than the co-tier interference [19]. Hence, in this paper, we will mainly focus on the co-tier interference caused by one SBS to another.

To mitigate co-tier interference, the sub-channel allocation is located in the SDN controller. The controller depends on periodic network status information, which can be obtained from the SCN. As soon as the sub-channel allocation is performed, the SDN controller applies the sub-channel allocation configuration, as shown in Fig. 2.

Here, we assume that. $\mathbf{N} = \{1, \ldots, N\}$ collects all the available orthogonal frequency sub-channel indices and N denotes the number of sub-channels in the network. Each SBS $f \in \mathbf{F}$ randomly selects N_f orthogonal frequency sub-channels serving U_f SUE units. The N_f sub-channels are the initial frequency resource of SBS f. As previously mentioned, all SBSs are considered to be deployed indoors, that is, inside the enterprise premises. In this work, we consider practical fading effects, including path loss, penetration loss and Rayleigh fading [30]. For a given sub-channel $n \in N_f$, the channel gain experienced over the link of the SUE units $u_f \in U_f$ served by SBS $f \in \mathbf{F}$ is obtained using (1):

$$G_{f,u_f}^{(n)} = PL_{f,u_f} D_{f,u_f}^{-\alpha} RF_{f,u_f}^{(n)}, \tag{1}$$

where PL_{f,u_f} and D_{f,u_f} respectively denote the path loss coefficient and the distance from SBS f to one of its SUE units, u_f, α is the path loss exponent, and $RF_{f,u_f}^{(n)}$ denotes the Rayleigh fading from SBS f to one of its SUE units, u_f, on sub-channel n.

Furthermore, for a given sub-channel $n \in N_f$, the interfering sub-channel gains experienced over the link of the SUE units $u_f \in U_f$ served by SBS $f \in F$ is obtained using (2):

$$G_{d,u_f}^{(n)} = PL_{d,u_f} D_{d,u_f}^{-\alpha} W_{d,u_f}^{-1} RF_{d,u_f}^{(n)}, \tag{2}$$

where W_{d,u_f}^{-1} denotes the internal wall penetration loss.

Therefore, the downlink rate achieved by all SUE units $u_f \in U_f$ associated with SBS f on sub-channel n under the non-cooperative scenario can be obtained using (3):

$$R_{f,u_f}^{(n)} = \sum_{n \in N_f} \sum_{u_f \in U_f} \log_2 \left(1 + \frac{P_{f,u_f}^{(n)} G_{f,u_f}^{(n)}}{\delta^2 + I_{\text{co-tier}}} \right), \tag{3}$$

where δ^2 is the variance of the Gaussian noise, $P_{f,u_f}^{(n)}$ is the downlink transmission power between SBS f and its SUE units u_f on sub-channel n, and $I_{\text{co-tier}}$ is the received total co-tier interference by the SUE units u_f from other SBSs on the serving sub-channel n, which is obtained using (4):

$$I_{\text{co-tier}} = \sum_{d \in \mathbf{F}, d \neq f} P_{d,u_f}^{(n)} G_{d,u_f}^{(n)}. \tag{4}$$

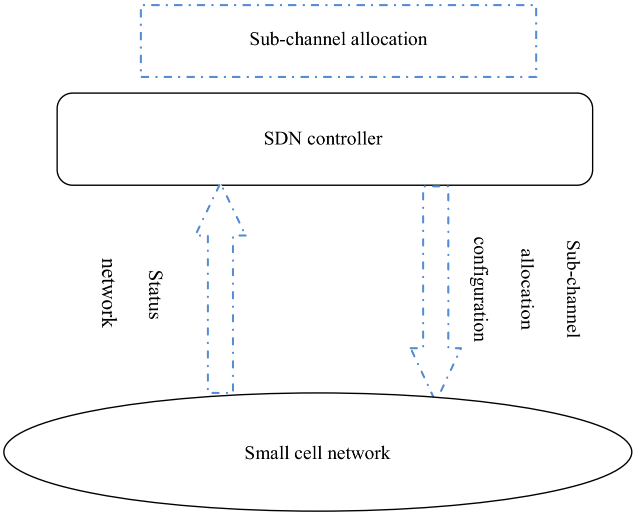

Fig. 2. Framework of sub-channel allocation using an SDN-based small cell network.

III. SDN-Based Hierarchical Agglomerative Clustering Formation for Interference Mitigation

In this section, we propose a novel SDN-based hierarchical agglomerative clustering (SDN-HAC) framework for SCNs, which is conducive to building a more flexible and effective interference mitigation system.

1. Cooperative Model of SDN-Based SBSs

Small cell densification is a promising scheme to meet the ever-growing traffic demand. The denser the SBS deployments become, the better the cooperative model can improve the network. Our previously proposed SDN-based cooperative network model [22] is based on the traditional network architecture. In this work, the cooperation among SBSs is based on the SDN architecture, as illustrated in Fig. 3. For figure clarity, the SUE units in the network are not shown.

The SDN controller adjusts the cooperation among SBSs by collecting network status information, such as available sub-channels, SBSs, and SUE units. It separates transmission handling within the data plane to make the cooperation viable in practice. Each set of cooperative SBSs is called a cluster, which is denoted here by C_l; therefore, in a cooperative model, each cluster consists of m SBSs. The set of all clusters is denoted by $C = \{C_1, C_2, \ldots, C_l\}$. Let $v(C_l)$ denote the value of each cluster. The condition for forming clusters is given in Definition 1.

Definition 1. If the sum of the values of all elements in the set $C = \{C_1, C_2, \ldots, C_l\}$ reaches the maximum, the set and its elements are designated by $C^* = \{C_1{}^*, C_2{}^*, \ldots, C_l{}^*\}$. Correspondingly, the value of each element is denoted by $v^*(C_l{}^*)$. At this point, the maximum is called the optimal clustering composition and is denoted by OCC*. Consequently, we have that $\text{OCC}^* = \sum_{l=1}^{L} v^*(C_l{}^*)$.

By Definition 1, we can obtain the optimal clustering composition, that is, $C_1{}^*, C_2{}^*, \ldots, C_l{}^*$. In addition, each cluster value $v(C_l)$ is independent of the elements of any other clusters selected in the optimal clustering composition. More specifically, we assume no externalities in our model. Therefore, each cluster exists in a state of isolation and by adopting simple arithmetic operations we can evaluate the benefits of merging one cluster or element with another. We will further explore the value $v(C_l)$ in a similarity criterion, in order to apply it to the large-scale data-clustering algorithm described below. SBSs within the same cluster jointly transmit messages to their users. The transmission rate of cluster C_l is obtained using (5):

$$v(C_1) = \sum_{f \in C_1} \sum_{n \in N_f} \sum_{u_f \in U_f} \tau_{f,u_f}^{(u)} \log_2 \left(1 + \frac{P_{f,u_f}^{(n)} G_{f,u_f}^{(n)}}{\delta^2 + 1_{\text{co-tier}}} \right), \quad (5)$$

where $\tau_{f,u_f}^{(n)}$ represents the fraction of total time occupied by the transmission between SBS f and SUE u_f over sub-channel n. Meanwhile, the corresponding co-tier interference term $I_{\text{co-tier}}$ can be rewritten as in (6):

$$I_{\text{co-tier}} = \sum_{\overline{C_l} \in \mathbf{C} \setminus C_l} \sum_{d \in C_l, d \neq f} P_{d,u_f}^{(n)} G_{d,u_f}^{(n)}. \quad (6)$$

In our work, if SUE units from different SBSs jointly occupy a sub-channel, these SBSs have the possibility of forming a cluster in order to mitigate co-tier interference;

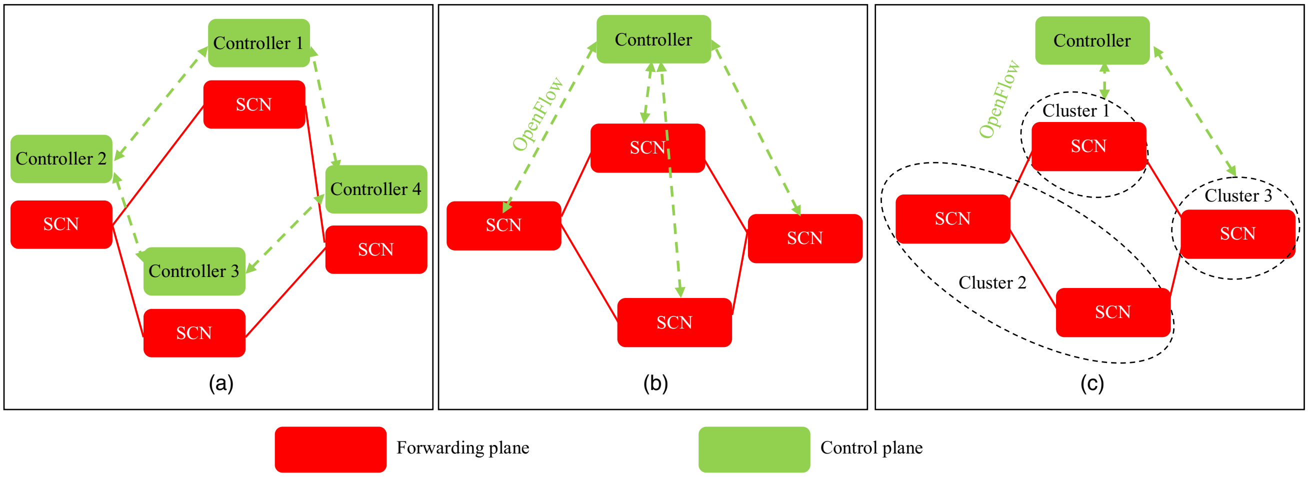

Fig. 3. Distributed control: (a) traditional network architecture. Centralized control: (b) SDN architecture and (c) proposed SDN-based cooperative network model.

otherwise, clusters cannot be formed. Consequently, the co-tier interference considered in this work comes only from the same cluster. To overcome this interference, we propose to employ cooperation among SBSs using an SDN-based hierarchical agglomerative clustering framework.

2. Cooperation between SBSs Using an SDN-Based Hierarchical Agglomerative Clustering Framework

To find the most suitable sub-channel allocation configuration with the least amount of interference within a dense small cell environment, we use the following two definitions:

Definition 2. Members in the same group or cluster should be similar, whereas members from different groups or clusters should be dissimilar. This property is called the similarity criterion.

The specific definition of similarity used in our work is based on whether SUE units belonging to different SBSs occupy the same sub-channel; if these SUE units occupy the same sub-channel, we consider them "similar." Meanwhile, these SUE units belong to different SBSs, which may be made to lie in the same cluster, as previously mentioned. The formulation of an appropriate similarity criterion to cluster SBSs is an important consideration. Therefore, we introduce a suitability function based on the value $v(C_l)$ [22].

Definition 3. Given two clusters C_l and C_m, the suitability function is defined using their values $v(C_l)$ and $v(C_m)$, and the value of their union set $v(\{C_l \cup C_m\})$, as follows:

$$S(C_l, C_m) = v(\{C_l \cup C_m\}) - v(C_l) - v(C_m). \quad (7)$$

The suitability function describes whether merging two clusters or two members is beneficial or not. If $S(C_l, C_m)$ is positive, the union set is useful to improve network performance, and we will therefore choose to merge; otherwise, a merge will not be done. In addition, the cluster suitability matrix $CS^{(h)}$ stores the value of each suitability function and is iteratively updated according to the changes in this function; h denotes the number of changes or hierarchies.

The proposed SDN-HAC algorithm is composed of three main phases: (i) the non-cooperative phase, where the cluster suitability matrix for each member pair and the iteration for cluster formation are initialized, as shown in the flowchart of Fig. 4. (ii) The main algorithm starts from the completely non-cooperative case: each cluster consists of a single member (Stage 1), and $CS^{(h)}$ is initialized with the suitability of the member pairs (Stage 2). (iii) The algorithm then enters into Stage 3: at each iteration, the most suitable pair of clusters is computed using (5) and (6); if joining a cluster pair is beneficial to the network system ($CS \geq 0$ and $|\mathbf{C}| > 1$), these clusters are discarded and replaced by their union set, thus obtaining a next level in the hierarchy. Otherwise, the algorithm terminates and the most suitable clusters are considered formed.

3. Properties of the Proposed Small Cells' SDN-HAC Algorithm

The main properties of the proposed SDN-HAC algorithm in terms of stability, convergence, and complexity will now be analyzed.

Property 1. The cluster formation process based on the suitability function converges to a stable state in a finite number of steps.

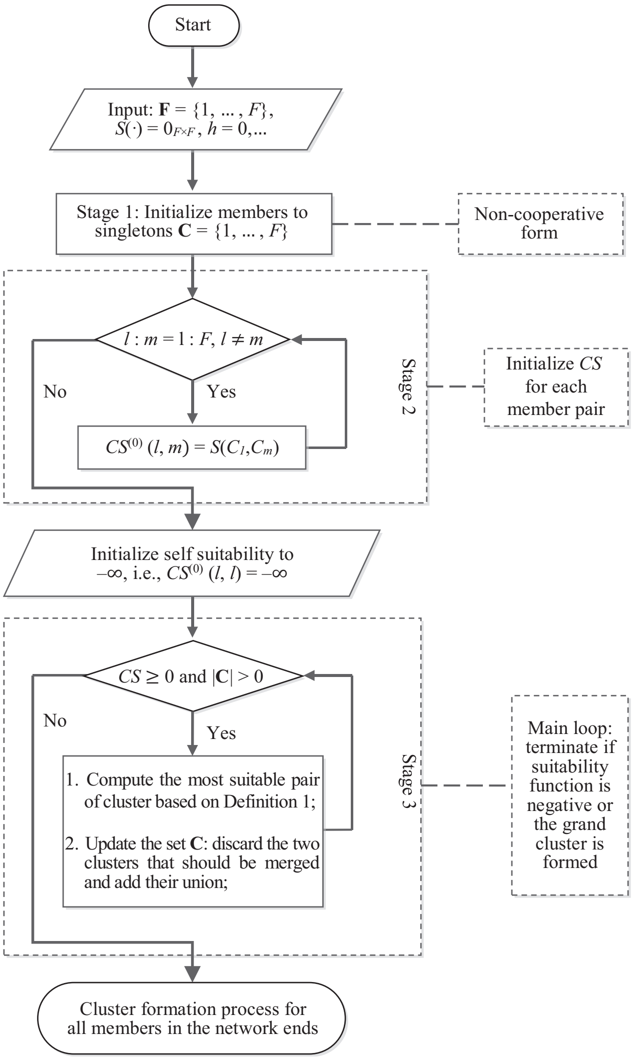

Fig. 4. Flowchart of the proposed SDN-based hierarchical agglomerative clustering framework.

Proof: Given that the number of elements (SBSs) in our proposed algorithm is finite, the number of possible clusters is also finite. Furthermore, the proposed algorithm always converges in, at most, F steps (F is the number of SBSs in the network, as previously defined). This is due to the fact that the proposed algorithm removes one single element per iteration and terminates if the grand cluster is formed or if the value of the suitability function becomes non-positive. In such a context, the cluster formation process based on the suitability function must converge to a final stable state in, at most, F steps. ■

Property 2. The order of complexity of the proposed SDN-SAC algorithm is $O(F^3)$ in the worst case.

Proof: The computational complexity of our proposed algorithm in a UD-SCN is closely related to the number of merges carried out by each independent SBS. As described in Section III.2, SBSs can only form clusters if they occupy the same sub-channels. Therefore, at iteration hierarchy h, the number of clusters is $F - h$. Then, at the next iteration hierarchy, $h + 1$, at most $\binom{F-h}{2} = \frac{(F-h)(F-h-1)}{2}$. cluster pairs should be considered. Furthermore, the total number of potential cluster pairs is $\sum_{h=0}^{F-1} \binom{F-h}{2} = \frac{(F-1)F(F+1)}{6}$. Therefore, the total number of merging requests of an agglomerative algorithm is proportional to F^3. That is, the complexity order of the proposed SDN-SAC algorithm is $O(F^3)$ in the worst case. ■

IV. Simulation Results and Analysis

To evaluate the proposed SDN-HAC algorithm, we used MATLAB to simulate a dense small cell environment composed of F SBSs randomly deployed in an indoor square area of 1,500 m × 1,500 m at a minimum distance of 50 m from each other. That is, we assumed that the coverage of an SBS was 50 m. In addition, we assumed that these SBSs were omnidirectional. The transmission power of the SBSs was set to 20 dBm, and each SBS was assigned four sub-channels, to separately serve four SUE units [19], [22], [28]. The total number of available sub-channels was set to $N = 20$. We considered practical fading effects, as described in Section II.

For the evaluation, we compared the performance of the proposed SDN-HAC algorithm against two other approaches: the hierarchical agglomerative clustering algorithm based on a traditional small cell network architecture (SC-HCA) [22], and a case of non-cooperative SBSs. In SC-HCA, the controller of each SBS obtains four suitable sub-channels based on the sub-channels of the other SBS controllers. This algorithm was implemented based on the traditional network architecture. In the non-cooperative approach, each SBS randomly obtains four sub-channels without any prioritization, and is only concerned with its own quality of service (QoS).

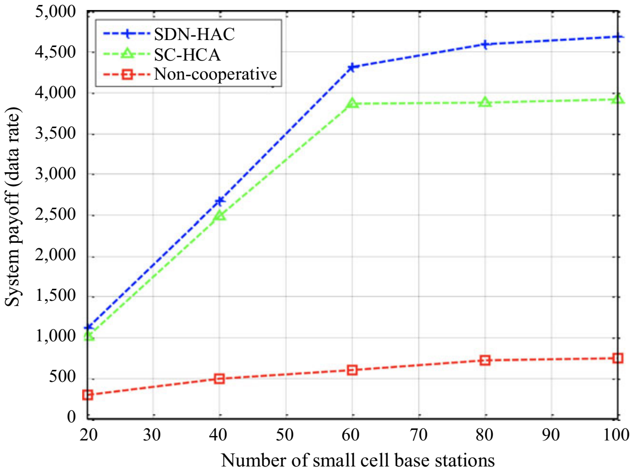

Fig. 5. Performance evaluation in terms of system payoff as a function of the number of SBSs.

Figure 5 shows the overall system payoff with regard to the data rate achieved by the proposed SDN-HAC algorithm as a function of the network's size F, and compares it with those of the other two approaches: SC-HCA and the non-cooperative scheme. We can clearly see in this figure that the proposed SDN-HAC performs better than both the SC-HCA algorithm and the non-cooperative scheme in terms of the achieved overall system payoff for the same number of SBSs. This is due to the fact that the proposed algorithm offers more potential options and provides more flexibility in the sub-channel assignment by allowing the SBSs to cooperate and form clusters. When $F = 80$, the proposed approach shows an improvement of 18.19% and 436.34% in terms of system payoff when compared with SC-HCA and the non-cooperative approach, respectively. Through cooperation and centralized sub-channel assignment control, the interference among the ultra-densely deployed SBSs is successfully eliminated, and it therefore becomes possible to utilize all the sub-channels more efficiently.

Figure 6 shows the convergence process of both the proposed SDN-HAC algorithm and the SC-HCA algorithm under different scenarios. As shown, the number of iterations of the proposed algorithm when convergence is achieved is approximately 32 and 17 for, respectively, $F = 40$ and $F = 20$. For SC-HCA, the

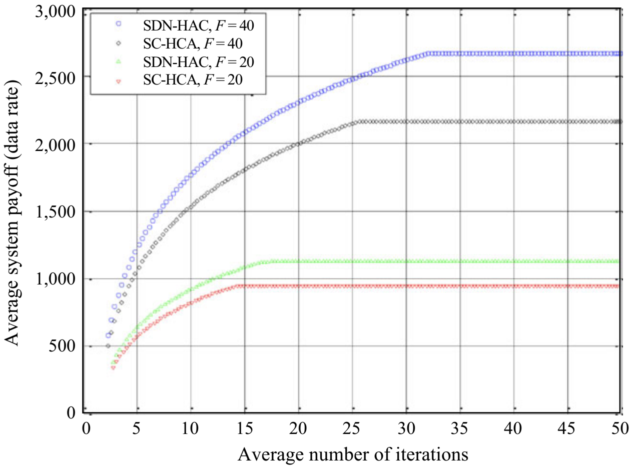

Fig. 6. Average system payoff versus average number of iterations under different scenarios.

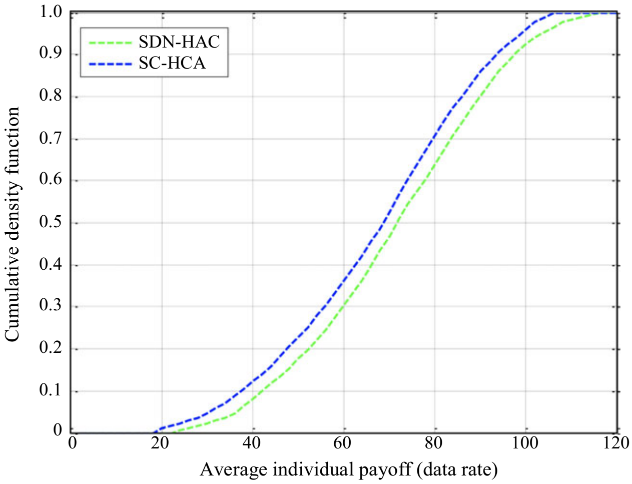

Fig. 7. Cumulative distribution function of the individual payoff per SBS (F = 40).

number of iterations is approximately 26 and 14 for $F = 40$ and $F = 20$, respectively. Even though the proposed algorithm needs a few more iterations than the SC-HCA algorithm to achieve the convergence state when $F = 20$ and $F = 40$, the required average number of iterations is in an acceptable range. Furthermore, we can observe that the proposed algorithm performs more efficiently than SC-HCA in terms of system payoff, as evidenced by the number of extra iterations. This result further corroborates the earlier analysis and the simulation results presented in Fig. 5.

Figure 7 shows the cumulative density function (CDF) of the average individual SBS payoffs afforded by the SDN-HAC and SC-HCA algorithms when the number of SBSs is set to $F = 40$. As is clearly shown, the proposed SDN-HAC yields an advantage on average individual payoff per SBS over the SC-HCA algorithm. For example, the desired value of the individual payoff from the proposed algorithm is 60, while the desired value is approximately 57 for the SC-HCA algorithm. This is because the proposed SDN-HAC algorithm performs the centralized sub-channel resource allocation based on the SDN controller, which provides more flexibility to the SBSs to form clusters, and thus further contributes to improve the individual payoff per SBS.

Figure 8 shows the system payoff in terms of the data rate, as the length of the SBSs' coverage square area A varies. The number of SBSs in the considered network is still set to $F = 40$. We compare the system payoff of the proposed SDN-HAC algorithm, the SC-HCA algorithm, and the non-cooperative scheme. We can see from Fig. 8 that the system payoff increases as the length of the SBSs' coverage square area A increases. This is due to the fact that the co-tier interference is mitigated when the SBSs are deployed over a larger coverage area. Hence, the system payoff is enhanced in most cases. Moreover, we can also see from Fig. 8 that, as the length of the SBSs' coverage square area A increases, the proposed SDN-HAC algorithm increases the performance advantage over the SC-HCA algorithm and the non-cooperative scheme.

Figure 9 shows a comparison of the proposed SDN-HAC algorithm with the SC-HCA algorithm and the non-cooperative scheme in terms of system payoff, as the total number of available sub-channels N varies. This simulation considers the existence of 20 SBSs in the network. The inset in the upper right of this figure is the enlarged result of the lower x-axis region of Fig. 9. From the results, we observe that the system payoff in the

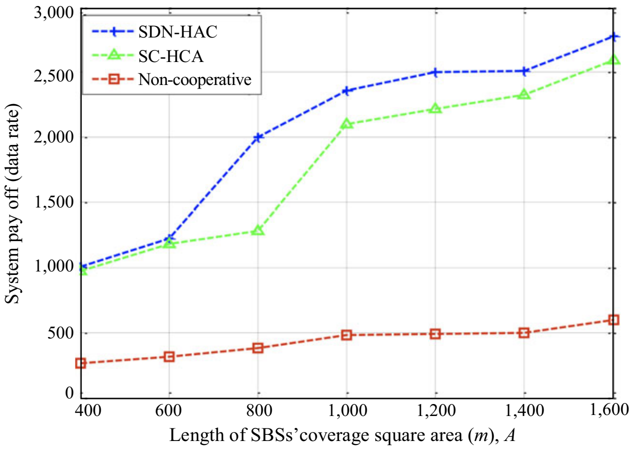

Fig. 8. System payoff as a function of the length of the SBSs' coverage square area (F = 40).

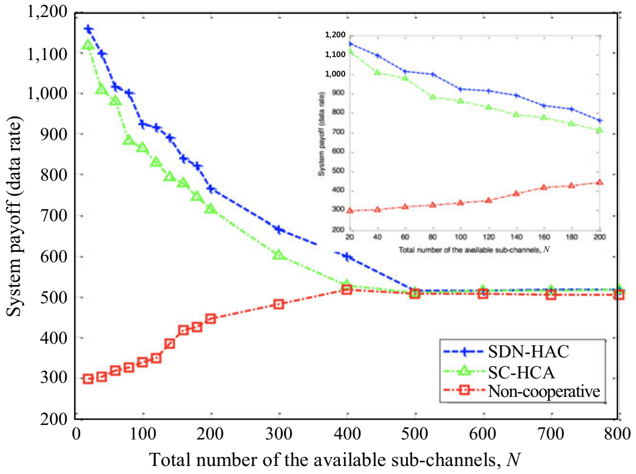

Fig. 9. System payoff as a function of the total number of available sub-channels (F = 20).

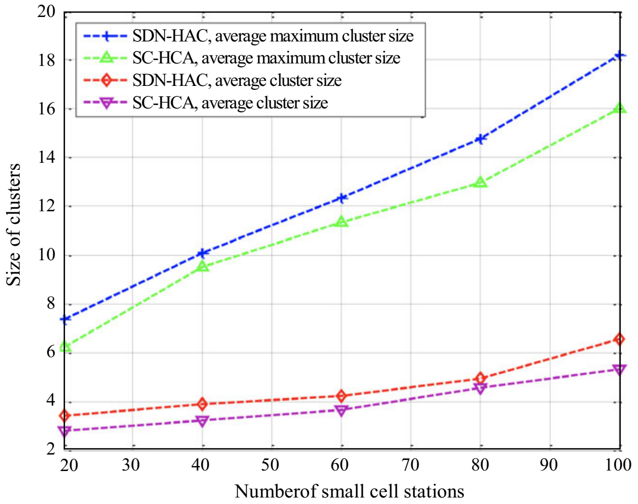

Fig. 10. Average maximum cluster size and average cluster size as a function of the number of SBSs F.

cooperative cases—that is, the proposed algorithm and the SC-HCA algorithm—decreases as the number of available sub-channels increases, while the system payoff in the non-cooperative case exhibits a slow upward trend. Moreover, when the total number of sub-channels N reaches a certain value (here, approximately 400 to 500 sub-channels), we notice that there is almost no difference among the three algorithms and the system payoffs overlap. Given the cooperation criterion, when the SBSs occupy the same sub-channels, there is the possibility of cluster formation. As described in the previous section, the major reason for this phenomenon is that the need for cooperation among SBSs greatly declines as the total number of sub-channels increases. Therefore, the advantage of cooperative algorithms is decreased in these conditions; the system payoff of the cooperative algorithms decreases and finally overlaps the non-cooperative case. Nevertheless, the performance advantage of our proposed SDN-HAC algorithm is still remarkable compared with the SC-HCA algorithm and the non-cooperative scheme when the total number of available sub-channels in the network system is below 500.

Figure 10 shows that, for both the proposed SDN-HAC algorithm and the SC-HCA algorithm, the average cluster size and the average maximum cluster size are affected by the number of SBSs. In fact, as the network size increases, both the average cluster size and the average maximum cluster size increase. This is because as the number of SBSs increases, the possibility of cooperation among SBSs also increases. Moreover, it is clearly apparent that the proposed algorithm exhibits the biggest cluster sizes, be it the average cluster size or the average maximum cluster size. This is due to the fact that the proposed SDN-HAC algorithm allows more SBSs to join the cooperative process, and thus forms larger clusters.

V. Conclusions

In this paper, we have described an algorithm based on cooperative SBSs that addresses the problems associated with spectrum assignment and interference mitigation in ultra-dense small cell environments. The proposed algorithm builds on an SDN-based ultra-dense small cell network where the SDN controller works as a central administrator to allocate the sub-channels. Adjacent SBSs may be combined into clusters based on a properly defined suitability function. Given that the proposed algorithm only needs to consider the computation of paired SBSs, it is more adequate to hyper-dense deployments of small cells. The algorithm's performance has been evaluated through simulations, and the results demonstrate that it achieves less interference and higher spectral efficiency in the considered network than the state-of-the-art approaches. The results show an improvement in terms of system payoff with respect to the traditional algorithms and non-cooperative scenarios by 18.19% and 436.34%, respectively.

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