Cooperation-based Interference Mitigation in Heterogeneous Cloud Radio Access Networks

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***Abstract*—In this paper, we propose a cooperation framework in heterogeneous cloud radio access networks (H-CRANs) to mitigate inter-tier interference. Specifically, small cell remote radio head (S-RRH) acts as the cognitive relay for multiple macrocell users (MUEs) which are primary users, and obtains a fraction of time slot from multiple MUEs as a reward. Through the cooperation, the S-RRHs can obtain extra spectrum resource for serving secondary users–small cell users (SUEs), while the MUEs can improve their transmission rates. Moreover, the inter-tier interference between macrocell networks and small cell networks can be mitigated via cooperation. The cooperation problem is formulated as a binary integer programming problem which is NP-hard. To solve this problem, we transform it to an equivalent many-to-one matching problem. Then, we achieve the near optimal solution by proposing a two-sided cooperator selection algorithm, which takes the benefits of both S-RRHs and MUEs into consideration. Simulation results show that the performance of the macrocell networks as well as small cell networks can be improved by adopting the proposed scheme, and the cooperator selection result is stable and close to the optimal solution.**

I. Introduction

To accommodate the soaring traffic at higher spectrum efficiency and data rate, heterogeneous networks (HetNets) have been proposed to expand coverage area and improve system performance of the next generation wireless networks [1]. It is predicted that more than 50 billion devices will be connected by 2020, and the wireless industry will face challenges in supporting 1000-fold traffic growth in the next decade [2]. Heterogeneous cloud radio access networks (H-CRANs), which integrate two separate network architectures: HetNets and cloud radio access networks (C-RANs), have emerged to further improve both spectrum and energy efficiency through interference mitigation and dynamic spectrum sharing [3].

H-CRANs inherit the tiered architecture of HetNets to increase spectrum reuse, while the merits of C-RANs enable controlling the networks in a centralized manner at lower expenditure. In C-RANs, a large number of low-cost remote radio heads (RRHs), which are connected to the base band unit (BBU) pool, are randomly deployed [4]. The resource allocation and interference management decisions are carried out at the BBU pool where cooperative processing schemes can be leveraged based on the cloud capabilities. In this way, C-RANs and HetNets are complementary in interference mitigation and resource allocation, which contribute to improved both spectrum and energy efficiency. However, the intra-tier interference among RRHs can be reduced with centralized cooperative processing in the BBU pool, while the inter-tier interference between small cell RRHs (S-RRHs) and macrocell RRH (Macro RRH) is still challenging in H-CRANs.

Extensive research efforts have been devoted to interference mitigation in HetNets [5]–[8]. In [6], the authors investigated interference mitigation with massive-MIMO in HetNets where three interference coordination strategies with low complexity are proposed. The authors in [7] addressed the co-channel control and interference mitigation problem using directional antennas by building a stochastic geometry model. In [8], the authors studied the inter-tier interference coordination for HetNets where a 3D beamforming transmission approach is used for MUEs. Alternatively, cognitive radio (CR) can be leveraged to better mitigate interference by pro-actively avoiding co-channel interference, which results in higher spectrum and energy efficiency. Specifically, cognitive HetNets are capable of performing spectrum sensing, power and frequency adjustment [9]. In cognitive HetNets, the small cell base stations (SBSs) have to avoid allocating occupied spectrum that belongs to the macrocell networks. The key idea of inter-tier interference mitigation in cognitive HetNets is that all small cell users (SUEs) which are secondary users should autonomously sense the spectrum band of the macrocell and report the sensing results. Therefore, the SBSs periodically allocate subframes for SUEs to perform spectrum sensing. However, in this case, spectrum sensing may not be accurate due to sensing errors (i.e., false alarm and miss detection), and spectrum handover is required for the SUEs when the macrocell users (MUEs) reappear. SUEs may either switch to another temporarily idle channel or wait to resume sending packets in the original channel. As a result, it is important to explore the cooperation framework between the macrocell networks and the small cell networks. To this end, several cooperation frameworks have been investigated. In [9], an SUE acts as a relay for an MUE. In return, the cooperative MUE grants the usage of a fraction of its superframe to the SUE, and the cooperation is formulated by a coalitional game. In [10], a quadrature signaling based cooperation scheme is proposed to reduce the interference between primary users and secondary users in cognitive radio networks. In [11], Park *et al.* proposed a joint user association scheme with cell cooperation that improves the performance of inner SBS users by reducing the inter-cell interference.

Nevertheless, the aforementioned works focus on interfer-

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ence mitigation in HetNets or CR networks. New models and schemes are needed for H-CRANs since they move the majority of basic network functionalities from the RRHs to the BBU. Lin *et al.* in [12] addressed the interference problem in H-CRANs with improper Gaussian signaling. Peng *et al.* in [3] proposed a contract-based interference coordination scheme for downlink transmissions in H-CRANs. However, the baseband signal processing functionality is deployed in both the macro base station and the BBU pool, which compromises the benefits of separated base station functions in C-RANs. Moreover, interference management in uplink transmissions is more challenging since all users can independently adjust their transmission powers. Hence, the transmission rates of all users will be different from one to another accordingly. In this paper, we propose a cooperation framework to mitigate interference for H-CRANs, and the contributions are summarized as follows.

- We propose a CR based cooperation framework for interference mitigation in H-CRANs, with the objective of maximizing data transmission utility at enhanced spectrum efficiency. The cognitive S-RRHs act as relays for MUEs while the cognitive SUEs dynamically adapt their transmission powers to reduce interference.
- We model the cooperation problem as a binary integer programming problem, which is NP-hard. Then, the problem is transformed into a many-to-one matching problem, which is solved by the proposed two-sided cooperator selection algorithm.
- We demonstrate the effectiveness of proposed algorithm in improving data transmission utility via extensive simulations. In particular, MUEs can obtain higher transmission rates, while S-RRHs can acquire more spectrum access opportunities for data transmission by serving SUEs. The inter-tier interference can be mitigated through cooperation as well.

The remainder of this paper is organized as follows: The system model is described in Section II. In Section III, a multiple cooperator selection problem in H-CRANs is formulated and analyzed. Numerical results are shown in Section IV. Finally, concluding remarks are given in Section V.

II. System Model

A. Network Model

We consider the uplink transmissions of an orthogonal frequency division multiple access (OFDMA) H-CRANs system in which one macro RRH is deployed, and multiple cognitive S-RRHs are temporarily formed to serve the surrounding SUEs which are searching for spectrum access opportunities. All the RRHs, including the macro RRH and the S-RRHs, are connected with the BBU pool via optical fibers or mmWave communications [13], as illustrated in Fig. 1. The red link is the backhaul link between core network and BBU pool, and the blue links are the fronthaul links between BBU pool and RRHs. The black solid lines and black dash lines represent the transmission links with and without cooperation, respectively. The small cell networks are overlaid with the macrocell networks' spectrum bands. CR technology can be adopted where each small cell senses the spectrum occupation of neighboring cells, and then access the spectrum via one of the disjoint subchannels, thus avoiding interference from adjacent small cells. Alternatively, the intra-tier interference in H-CRANs can be reduced with centralized cooperative processing in the BBU pool. Let $\mathcal{M} = \{1, 2, ..., M\}$ denote the set of MUEs within the macrocell and let $\mathcal{K} = \{1, 2, ..., K\}$ denote the set of S-RRHs. Each S-RRH serves a set of SUEs which are close to it, and such a set of SUEs is expressed by set $\mathcal{N}_k$. Accordingly, each cellular (as shown in Fig. 1 with the biggest circle) has K sets of SUEs $\mathcal{N} = \{\mathcal{N}_1, \mathcal{N}_2, \ldots, \mathcal{N}_K\}$. $\mathcal{N}_k = \{1, 2, \ldots, |\mathcal{N}_k|\}$ where $|\mathcal{N}_k|$ denote the cardinality of set $\mathcal{N}_k$. We consider the closed spectrum access mode that MUEs are granted to communicate with the S-RRH after the cooperation relationship between MUEs and S-RRH has been established.

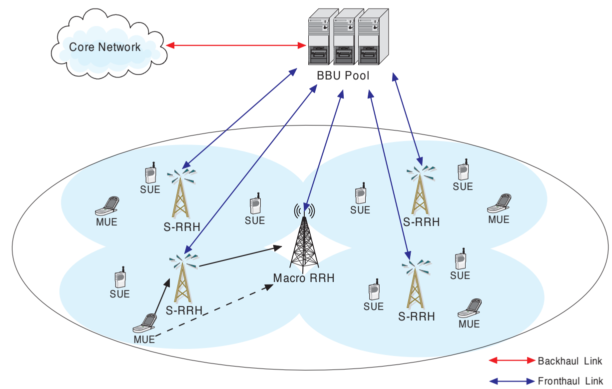

Fig. 1. Scenario of H-CRAN.

B. Channel Model

The cooperation between MUEs and S-RRHs operates in a time-slotted manner. The channels are considered to be stable during a fixed time slot T, but vary independently from one slot to another. It is assumed that the channel state information (CSI) is available. Such assumptions are commonly used, but in practical H-CRANs, CSI needs to be estimated by exploiting techniques such as minimum mean-square-error estimation, least squares estimation and maximum-likelihood estimation [14].

1) Non-Cooperation Mode: In the non-cooperation mode, the utility of transmission from MUE$_m$ ($m \in \mathcal{M}$) to the macro RRH can be written as:

$$U_m = TB_m \log_2 \left(1 + \frac{h_{m,0}^2 P_m}{\sum_{n \epsilon \Theta_m} h_{n,0}^2 P_n + \sigma^2}\right) \qquad (1)$$

where B_m is the bandwidth, and T represents the duration of one time slot. P_m is the transmission power of MUE$_m$, and P_n is the transmission power of SUE$_n$ without cooperation. The channel fading coefficients from MUE$_m$ to the macro RRH and from SUE$_n$ to the macro RRH are denoted by $h_{m,0}$ and

$h_{n,0}$, respectively. $n \in \Theta_m$ is the set of SUEs operating on the same subchannel with MUE_m, and σ^2 is the variance of the additive white Gaussian noise.

Mitigating interference is a crucial issue in HetNets, especially in closed access mode that gives permission to register a user with an S-RRH. In this case, any unregistered users approaching the S-RRH experiences harmful interference. The utility of SUE_n ($n \in \mathcal{N}_k$) transmitting to the S-RRH_k ($k \in \mathcal{K}$) is calculated by

$$U_n^k = TB_n^k \log_2 \left(1 + \frac{h_{n,k}^2 P_n}{\sum_{m \epsilon \Psi_n} h_{m,k}^2 P_m + \sigma^2} \right). \tag{2}$$

$h_{n,k}$ and $h_{m,k}$ represent the channel fading coefficients from SUE_n to S-RRH_k and from MUE_m to S-RRH_k, respectively. $m \in \Psi_n$ is the set of MUEs operating on the same subchannel with SUE_n.

2) Cooperation Mode: Cooperation is adopted between macrocell network and small cell network to improve both parties' utilities. Therefore, in the cooperation mode, the utility of MUE_m cooperating with S-RRH_k is expressed as

$$\widetilde{U}_m^k = \alpha_k T B_m \log_2 \left(1 + \frac{1}{\sigma^2} \cdot \frac{h_{m,k}^2 h_{k,0}^2 P_m P_k}{h_{m,k}^2 P_m + h_{k,0}^2 P_k + \sigma^2} \right). \tag{3}$$

P_k is the transmission power of S-RRH_k, and α_k is a time fraction factor of S-RRH_k. $h_{m,k}$ and $h_{k,0}$ denote the channel fading coefficients from MUE_m to S-RRH_k and the from S-RRH_k to macro RRH, respectively.

Correspondingly, the utility of SUE_n associated with S-RRH_k gained through cooperation with the MUE_m is shown as

$$\widetilde{U}_n^k = (1 - \alpha_k) T \widetilde{B}_n^k \log_2 \left(1 + \frac{h_{n,k}^2 \widetilde{P}_n}{\sum_{m \in \Phi_n} h_{m,k}^2 P_m + \sigma^2} \right) \tag{4}$$

where $\widetilde{B}_n^k = \frac{B_m q_k}{|\mathcal{N}_k|}$, $\Phi_n \subseteq \Psi_n$ and Φ_n is the set of MUEs operating on the same subchannel with SUE_n but not cooperating with the S-RRH_k. $\widetilde{P}_n$ denotes the transmission power of SUE_n with cooperation. $|\mathcal{N}_k|$ is the number of SUEs which are served by S-RRH_k, and q_k is the number of MUEs that S-RRH_k cooperates with.

III. Cooperator Selection Strategy

A. Problem Formulation

The small cell networks are temporarily formed based on the spectrum requirement from geographically close SUEs. The cognitive S-RRHs cooperate with the MUEs which are suffering from a bad throughput performance. The S-RRHs operate as relays to help MUEs transmit data since the S-RRHs have better relaying capability than that of the SUEs. In return, the S-RRHs acquire extra spectrum access opportunities for serving SUEs. The cooperation between MUEs and S-RRHs is a win-to-win game in that the MUEs can improve their performance, and the S-RRHs can help SUEs to acquire more spectrum resource.

When the BBU pool performs resource allocation, cooperative partner selection is also considered. During the cooperation process, S-RRH_k cooperates with multiple MUEs within interval $\alpha_k T$. In return, the S-RRH_k acquires the remaining time slot $(1 - \alpha_k) T$ for its serving SUEs. Note that different S-RRHs have distinct α_k. Therefore, the optimization problem of our proposed cooperation framework can be formulated as follows:

$$\begin{aligned} (\mathcal{P}): \quad \underset{x_{k,m}}{\text{maximize}} \quad & \sum_{k \in \mathcal{K}} \sum_{m \in \mathcal{M}} x_{k,m} \left(\widetilde{U}_m^k + \sum_{n \in \mathcal{N}_k} \widetilde{U}_n^k \right) \\ \text{subject to} \quad & \sum_{k \in \mathcal{K}} x_{k,m} \leq 1 \\ & \sum_{m \in \mathcal{M}} x_{k,m} \leq q_k \\ & x_{k,m} \in \{0, 1\} \end{aligned} \tag{5}$$

where $x_{k,m} = 1$ indicates that S-RRH_k is assigned to cooperate with MUE_m. Otherwise, $x_{k,m} = 0$. The first constraint denotes MUE_m can be associated with at most one S-RRH. q_k is the maximum number of MUEs the S-RRH_k choose to cooperate with, and the second constraint means that each S-RRH_k can cooperate with at most q_k MUEs.

The formulated binary integer optimization problem is an NP-hard problem (one of Karp's 21 NP-complete problems [15]), so we transform it into a many-to-one matching problem. The MUEs, of which transmission condition is poor, join in the cooperation to improve their performance. The S-RRHs that require spectrum access opportunities also join a stable matching set with MUEs. Afterwards, the BBU pool generates the cooperating preference lists of MUEs and S-RRHs separately. Subsequently, by adopting the two-sided cooperator selection algorithm, matched cooperation pairs between one S-RRH and multiple MUEs can be obtained.

B. Many-to-One Matching

It is noticed that the optimization problem $\mathcal{P}$ involves two sets of agents: K S-RRHs which are denoted by $\mathcal{K} = \{1, 2, \ldots, K\}$, and M MUEs which are expressed by $\mathcal{M} = \{1, 2, \ldots, M\}$. We convert the optimization problem into a many-to-one matching problem in which each agent has a transitive and strict preference list of the acceptable agents on the other side. Let $\Gamma \subseteq \mathcal{K} \times \mathcal{M}$ denote the set of acceptable pairs. q_k is a positive integer which denotes the quota, in other words, it is allowed up to q_k MUEs cooperating with S-RRH k. Without loss of generality, we assume that (i) k finds m acceptable if and only if m finds k acceptable, and in this case, we say that (m, k) is an acceptable pair; (ii) S-RRH k finds at least q_k MUEs acceptable, and each MUE finds one S-RRH acceptable. Note that we consider the preference lists in which the S-RRHs have preferences over individual MUEs, not over groups of MUEs.

The two-sided many-to-one matching approach takes both parties' interests into consideration. Therefore, each user has a preference ranking list of acceptable users on the other side. Each user in set $\mathcal{K}$ (or $\mathcal{M}$) has preference over each user in set

$\mathcal{M}$ (or $\mathcal{K}$). Let $\psi(k)$ be the preference function of user k in set $\mathcal{K}$, and let $\varphi(m)$ be the preference function of user m in set $\mathcal{M}$. Hence, the S-RRHs have a preference set $\psi(k)$ for MUEs, which are sorted by their gained utility through cooperation with MUEs represented by $\sum_{n\in\mathcal{N}_k}\widetilde{U}_n^k$. Each MUE also has its own preference set $\varphi(m)$, which are ordered by the expression $\widetilde{U}_m^k$. The incidence matrix $\mathcal{X}$ is a subset of μ and is defined by: $x_{k,m}=1$, if $(k,m)\in\mu$, and $x_{k,m}=0$ otherwise. The objective of the matching is to find a stable matching solution. The following problem formulation contains a straightforward formulation of a stable matching in terms of its incidence matrix. It is evident that μ is a stable matching of (Γ,q_k) if and only if its incidence matrix x satisfies the following inequalities:

$$\sum_{k:(k,m)\in\Gamma} x_{k,m}\leq 1,\ \forall m\in\mathcal{M} \tag{6}$$

$$\sum_{m:(k,m)\in\Gamma} x_{k,m}\leq q_k,\ \forall k\in\mathcal{K} \tag{7}$$

$$q_k x_{k,m}+q_k\sum_{i\succ_m k} x_{i,m}+\sum_{j\succ_k m} x_{k,j}\geq q_k,\ \forall (k,m)\in\Gamma \tag{8}$$

Indeed, the first two inequalities ensure that μ is a matching, and the last inequality guarantees that the matching is stable. Expression $i\succ_z j$ represents user z prefers i to j.

Before we proceed to the proposed two-sided cooperator selection algorithm, we have two related theorems as follows.

Theorem 1. *A pair $(k,m)\in\Gamma$ blocks μ if (i) k prefers m to at least one of its assigned MUEs in μ, or if k is assigned fewer than q_k MUEs, and (ii) m prefers k to its assigned S-RRH in μ, or if m is unmatched.*

Theorem 2. *A matching result μ is stable if it is not blocked by any pair of users.*

C. Two-sided Cooperator Selection Algorithm

The two-sided cooperator selection algorithm is performed to solve the cooperation problem, and it can be summarized by the following steps: First, the transmission rates of MUEs obtained by cooperating with S-RRH are calculated to get the preference cooperating S-RRHs lists of all MUEs, and the preference from the highest to lowest are sorted. In addition, the S-RRHs have the privilege to choose the MUEs and form the preference lists based on the MUEs' assigned resource. Each S-RRH proposes to its top-ranked choice (If an S-RRH has a quota of q_k, then the q_k MUEs are top-ranked on its ranking list). Afterwards, the MUE checks whether one of the proposals from the S-RRHs is its most preferred cooperator according to its preference ranking list. If no such matchings is found, the algorithm proceeds to the next step, where the second ranked MUE on each S-RRH's ranking list is matched with the top-ranked MUEs on the S-RRH's list. In any step where no matches is found, the algorithm proceeds to the next step. Otherwise, the matched pairs are under the tentative-assignment-and-update state. Finally, when the pairs are under the tentative-assignment-and-update state from the ℓth step, the tentative matched pairs, i.e., S-RRHs and MUEs, are updated in the following way.

- Any S-RRH who ranks lower than the MUE's tentatively assigned cooperator is deleted from its ranking list, i.e., the updated ranking of the MUE who is tentatively assigned to its ℓth choice lists only its ℓth first choice;
- MUE is deleted from the ranking of any S-RRH who was deleted from the MUE's ranking list.

According to the above statement, we specify the algorithm in Algorithm 1.

Algorithm 1 Two-sided Cooperator Selection Algorithm.

Input: A set of S-RRHs $\mathcal{K}$, a set of MUEs $\mathcal{M}$, and preference ranking lists $\psi(k)$, $\varphi(m)$ of the S-RRHs and MUEs, respectively.
Initialize $\mu=\emptyset$ and $\ell=1$;

Output: The cooperation pairs selection, i.e., many-to-one matching result μ;

while (S-RRH k is not fully subscribed) and ($\psi(k)\neq\emptyset$) **do**
  S-RRH k proposes to the MUEs who are the first ℓth choice in the preference ranking list $\psi(k)$.
  if S-RRH k is the first choice in MUE m's preference ranking list $\varphi(m)$ **then**
    $\mu=\mu\cup\{(k,m)\}$, and update the ranking lists $\psi(k)$, $\varphi(m)$ of the S-RRHs and MUEs, respectively;
  else
    $\ell=\ell+1$, and go back to step 2;
  end if
end while
μ is a stable matching.

Based on the Theorem 1 and Theorem 2 in section III-B, we have the following propositions.

Proposition 1. *Stable matching can be obtained based on the two-sided cooperator selection algorithm.*

Proof. We prove the proposition by contradiction. Let μ be the matching result acquired using the two-sided cooperator selection algorithm. Suppose (k,m) will block μ, i.e., S-RRH k and MUE m are not matched indicating that the pair (k,m) does not belong to μ, but they prefer each other more. Therefore, MUE m prefers S-RRH k more than other S-RRHs on its preference ranking list $\varphi(m)$, i.e., $k\succ_m\mu(m)$. Moreover, S-RRH k must have proposed to MUE m before the matching algorithm stops. However, they do not match each other in the matching result μ, which suggests that MUE m must reject the proposal of S-RRH k. In this case, there must be some S-RRH k' who has a higher priority in MUE m's preference ranking list in μ. As a result, (k,m) will not block μ, which contradicts the assumption. Hence, matching result μ is a stable matching since there is no user blocking it. □

Proposition 2. *Stable matching for the two-sided cooperation pair selection problem is unique.*

Proof. We prove the proposition by induction on M. Let K be the number of S-RRHs with quota q_k, M be the number of MUEs, and μ be the matching for matrix $\Gamma_{\mathcal{K}\times\mathcal{M}}$. When $M=1$, the stable matching is definitely unique since the first and best MUEs will be assigned to the only S-RRH; when $M \geq 2$, let μ be the matching result which can make the S-RRHs choose the nearest MUEs for Γ, and let μ' be the matching we attain by deleting a S-RRH k and MUE m to attain Γ'. Suppose μ' is the unique stable matching for Γ'. If μ is a stable matching, then $\mu(k)=m$, and $\mu \setminus \{(k,m)\}$ must be a stable matching. By induction, we can conclude that $\mu := \mu' \cup \{(k,m)\}$ is the unique stable matching for Γ. Therefore, μ is the unique stable matching for Γ. $\square$

Proposition 3. *The proposed two-sided cooperator matching scheme always converges to a stable matching.*

Proof. To see that the scheme converges, note that each MUE can only be rejected at most K times. Consequently, for each MUE, there exists ℓ high enough such that in all rounds of the algorithm past ℓ, the MUE is assigned the same S-RRH, so the pointwise limit exists. To see that the limit is a matching, we only have to prove that the measure of MUEs assigned to each S-RRH is no more than its capacity. At each round ℓ of the algorithm, let R_ℓ be the measure of rejected MUEs. Again, because no MUE can be rejected more than K times, we have $R_\ell \to 0$. But at round ℓ, the excess of MUEs assigned to each S-RRH has to be at most R_ℓ, so in the limit, each S-RRH is assigned at most its quota. Also, if the measure is less than the quota, then we know the S-RRH has not rejected any MUEs throughout the algorithm. $\square$

IV. Numerical Results

In this section, the proposed cooperation scheme is evaluated via extensive simulations. The performance and interference level of MUEs and SUEs with and without cooperation are compared, respectively. In addition, the performance of proposed two-sided cooperator selection algorithm is compared with the optimal solution.

We consider an H-CRAN with single hexagonal macrocell consisting of one macro-RRH, K S-RRHs, M MUEs and N SUEs. The SUEs are in coexistence with the MUEs on the same bandwidth 20 MHz. The macro RRH serves MUEs scheduled over M OFDMA subcarriers with equal bandwidth. Each S-RRH serves 10 SUEs which also uses OFDMA spectrum access manner. A closed access policy is adopted at each S-RRH. The maximum transmission power at each S-RRH is set to 40 dBm, and the power limitation of MUEs is set to 30 dBm. The transmission powers of SUEs with and without cooperation are 30 dBm and 20 dBm, respectively. We assume that $h_{m,n}$ only includes the propagation gain between node m and n which is calculated by $|h_{m,n}|^2 = d_{m,n}^{-\gamma}$ for simplicity. $d_{m,n}$ is the distance from node m to n with unit meter and path loss exponent γ is set to 4. The noise power is 10^{-13} W. α can be different from one S-RRH to another, but we consider $\alpha = 0.5$.

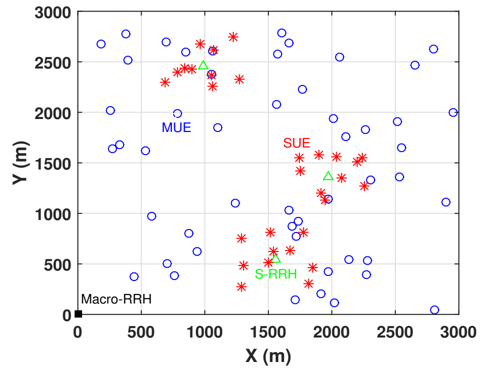

Fig. 2. H-CRAN deployment.

In Fig. 2, a simple H-CRAN scenario is illustrated. The macro RRH is represented by a solid square which is located at the origin. MUEs and S-RRHs are deployed uniformly on the 3000×3000 m^2 area, and the S-RRHs are represented by the green triangles serving as the center of a disc of radius 300 m in which SUEs are randomly located. Red stars denote the SUEs, and blue circles represent the MUEs. The number of MUEs and S-RRHs are 50 and 3, respectively. Each S-RRH serves 10 SUEs, and the number of SUEs is 30 accordingly.

As shown in Fig. 3, the number of S-RRHs varies from 5 to 15, and each S-RRH serves 10 SUEs. Accordingly, the number of SUEs varies from 50 to 150. The quota of the S-RRH is $q_k = 3$. In our simulation, the preference ranking lists of the S-RRHs and MUEs are obtained according to the H-CRAN configuration. In Fig. 3, we compare the average utility of MUEs and SUEs with and without cooperation, respectively. The red line with circles represents the average utility of MUEs which cooperate with S-RRHs, and the value increases as the number of S-RRHs becomes larger because cooperators with better conditions are selected and more MUEs being involved in the cooperation. Moreover, it can be observed that the average utility obtained with cooperation outperforms that without cooperation. Not only the S-RRHs contribute to that by relaying transmission, but also the cooperation between S-RRHs and MUEs mitigates the interference to both small cell and macro cell networks.

In Fig. 4, the interferences to MUE and SUE (with and without cooperation) are illustrated, respectively. It is indicated that the interference to both MUE and SUE are mitigated due to the cooperation between the S-RRH and MUEs. The reason for the interference mitigation of the SUE is that the cooperative MUEs stop the continuous retransmissions to the macro RRH since the S-RRH help them relay their traffic to the macro RRH.

We compare the scenario of our proposed two-sided cooperator selection algorithm and the Hungarian algorithm which gives the optimal solutions when $q_k = 1$. The number of S-RRHs is $K = 10$, and the number of MUEs M varies from 10 to 100. As shown in Fig. 5, the blue stars represent the optimal results obtained by the Hungarian method, and the

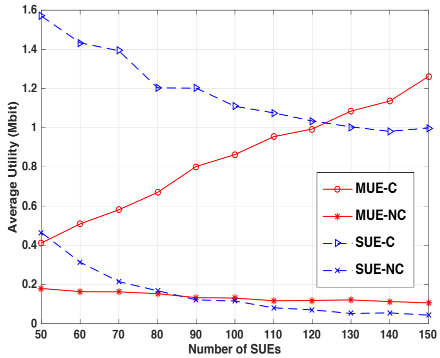

Fig. 3. Utility comparison with and without cooperation.

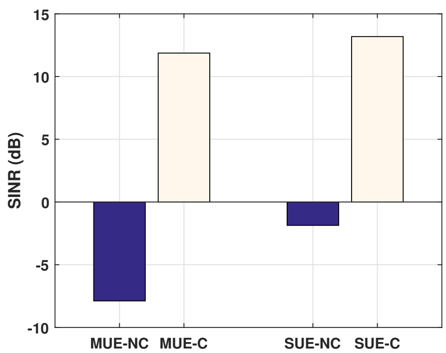

Fig. 4. Interference to MUE and SUE with and without cooperation.

red circles are the results obtained by our proposed selection method, which are very close to the optimal solutions.

V. Concluding Remarks

In this paper, we have proposed a CR based cooperation strategy for interference mitigation in H-CRAN. The cooperation problem is first formulated as a binary integer programming, and then transformed to a many-to-one matching problem. We solved the matching by our proposed cooperator selection scheme that takes both S-RRHs' and MUEs' benefits into consideration. In addition, the inter-tier interference can also be reduced. One of the applications by adopting our proposed cooperation framework is that the S-RRH can cache the data from helping the MUEs if needed, which can reduce the traffic of fronthaul links. Simulation results show that the data transmission utility obtained by our proposed approach can reach to the near optimal performance in H-CRAN, and cooperation can improve both the MUEs' and SUEs' utilities compared with the noncooperation solution. For our future work, we will optimize the value of cooperation time fraction α and transmission power of S-RRHs to further improve the cooperation utility.

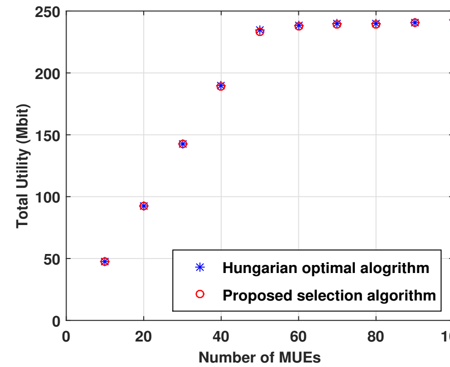

Fig. 5. Matching results of our proposed algorithm compared with that of the optimal algorithm.

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