Load-Sharing based on Relay-aided Cooperative Modeling in Uplink Two-Tier Cellular Networks

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***Abstract*—In this paper, we study the relay-aided cooperative modeling that supports the load-sharing in uplink two-tier cellular networks. In our model, users in heavily loaded macrocell are shifted to lightly loaded smallcells with the assistance of relay users to mitigate Signal to Interference plus Noise Ratio (SINR) degradation problem in conventional direct handover. In order to promote relaying data of users which are selfish and rational, a trading exchange model based on Stackelberg game is proposed to optimize strategies of users. Relay users have pricing-based strategies on theirs power unit while shifted heavily loaded macrocell users have strategies to buy power levels of relay users. Optimal strategies are investigated using the backward induction analysis. Specifically, problems of NP-hard combinatorial optimization in relay user selections in the game are solved with a distributed algorithm based on matching theory. We intensively evaluate our proposed model by simulating it in Matlab which shows the efficiency of our proposal.**

Keywords*—*Two-tier cellular networks, Stackelberg game, load-sharing, uplink transmission, matching theory.

I. INTRODUCTION

Next generation wireless networks such as the emerging fifth generation (5G) systems are promised to provide higher data rates to mobile users compared to fourth generation (4G) [1]. It is well established that 4G networks have just reached the theoretical limit on the data rate with current technologies. These technologies are being complemented in the 5G wireless system by designing and developing new radio concepts to accommodate higher data rates, larger network capacity, higher energy efficiency, and higher mobility necessary to meet the new and challenging requirements of new wireless application. Various promising technologies are proposed to incorporate 5G wireless communication systems such as massive MIMO, energy-efficient communications, relay-aided cooperative communication, smallcells network, trading exchange models, and cognitive radio networks.

The smallcell networks such as femtocells and picocells are promising methods to improve both spectrum efficiency and network capacity because they can act as an enabler for load-sharing in heavily crowded cells [2]. The smallcells deployment poses a number of challenges which needs to be addressed to enhance the overall system performance: 1) How to share traffic-load among cells, i.e. efficiently sharing traffic-load between heavily loaded cells and lightly loaded cells? 2) Providing high quality of uplink data connection to mobile users which lie at border coverage of the cells' base station? 3) How to promote cooperation among mobile users where users are selfish and rational in providing high quality of uplink transmit rate of mobile users? One approach to address these problem is shifting technique combined with relay-aided cooperative modeling that improves performance in poor coverage areas by enabling ubiquitous coverage even for users in the most unfavorable channel conditions. Several modes of relay-aid communication have studied in the literature, including fixed relay station, mobile relay station, and using other user equipments as relay nodes [3]–[6]. Most of existing results are derived for the fixed relay stations and mobile station relay [3], [4]. Using other user equipment as relay nodes are derived to support the load-sharing among cells in downlink cellular network where relay user selections are performed at base stations [5]. The user-assisted relaying in uplink cellular networks are also studied with the aim of measuring the improvements that can be achieved in terms of throughput and energy saving [6].

In our work, we propose a cooperation model supporting load-sharing among a heavily loaded macrocell and multiple lightly loaded smallcells. In details a relay-aided cooperative model is applied to improve uplink data rate of heavily loaded macrocell users by helps of relay users in lightly loaded smallcells. In order to promote cooperation where users are selfish and rational, a trading exchange model is employed based on two-stages Stackelberg game [5], [7]. In [7], we considered a cooperative model where a heavily loaded macrocell user is shifted to the lightly loaded smallcell with assistances from relay users. But problems of multiple heavily loaded macrocell users shifting to lightly loaded smallcells by helping of selfish and rational relay users has not been solved yet. The novel contribution different from the previous work [7] are as follows:

- We study the cooperation model in which multiple heavily loaded macrocell users are shifted to lightly loaded smallcells with help from multiple relay users.
- A trading exchange model is proposed based on two-stage Stackelberg game model to promote relaying data of relay users and mitigate SINR degradation problem in direct handover of the heavily loaded macrocell users.
- The NP-hard optimization problem of relay user selection in the Stackelberg game are solved based on matching theory [8]. A distributed algorithm is proposed to find optimal handover strategies where users' decision selfishly and rationally interact in a way that maximize their utilities.

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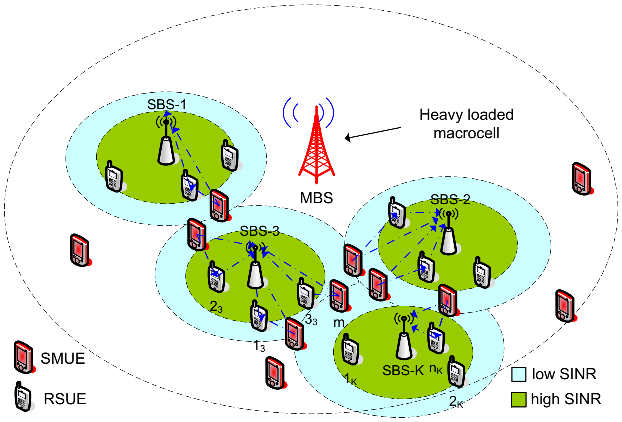

Fig. 1: System model

The system level simulation results who clearly that our proposal with cooperative model based on Stackelberg game approach and matching algorithm for supporting load-sharing among macrocell and smallcells.

The rest of this paper is organized as follows. The problem statement are presented in section II. The utility functions of heavily loaded macrocell users and relay users are constructed based on Stackelberg game model in section III. In section IV, we discuss solution of the game to optimize strategies of both heavily loaded macrocell users and relay users. Numerical results and discussions are illustrated in section V. Finally, section VI provides conclusion and future works.

II. System model

We consider an uplink two-tier network consisting of a heavily loaded macrocell base station (MBS) and a set of $\mathcal{K} = \{1, 2, ..., K\}$ lightly loaded smallcell base stations (SBSs) as shown in Fig. 1. In our work, a set of $\mathcal{M} = \{1, 2, ..., M\}$ shifted macrcocell users (SMUEs) that cannot be served by the MBS due to BS overloading are shifted to SBSs. In addition, these SMUEs lie at border coverage of nearby lightly loaded SBSs which leads to SINR degradation in direct handover. In order to mitigate SINR degradation problem, these SMUEs need assistance by the nearby relay smallcell user equipments (RSUEs) inside SBSs' service range, which all have the potential to act as relay users to help SMUEs in achieving higher data rate than direct connection. Let $\mathcal{N}_k$ denotes a set of RSUEs in each SBS k and $\mathcal{N} = \cup_{k\in\mathcal{K}}\mathcal{N}_k$. Assuming that the considered system is time-slotted and SBSs have enough capacity to receive all connection requesting from SMUEs. The decisions of SMUEs and RSUEs are made at the beginning of each time slot. Moreover, we assume that orthogonal channels are allocated to different SMUEs for the duration of the data transmission.

In order to successfully transmit data, each SMUE can transmit its data to a SBS via either of two following types of transmission.

Direct transmission without relay. In this type the SMUE establishes a connection to the SBS directly. Based on the Shannon capacity [9], the data rate of SMUE m connects to SBS k is computed as follows:

$$R^{\mathrm{d}}_{m,k} = W_m \log_2\left(1 + \frac{P_m |h_{m,k}|^2}{\Gamma\sigma^2}\right), \quad (1)$$

where W_m is the bandwidth of channel that is registered by SMUE m, P_m is the maximum power level of SMUE m's when the handover occurs, $|h_{m,k}|^2$ is the channel gain between SMUE m and SBS k which depend on the propagation loss factor, σ^2 is the Gaussian noise at SBS k, and Γ denotes the SINR gap to capacity. Here, the SINR is typically a function of the desired bit error ratio (BER), the coding gain and noise margin, e.g., $\Gamma = \frac{-\ln(5\mathrm{BER})}{1.5}$ in M-QAM (Quadrature Amplitude Modulation).

The cooperative transmission using relay users. In this case the data transmission of SMUE $m \in \mathcal{N}$ is transmitted by assisting relay of RSUE n_k. The amplify-and-forward (*AF*) protocol is applied in the relay transmission due to its simple and practical operation using two stages as in [10]. We treat one input and two outputs complex Gaussian noise channel by using maximal ratio combining when SMUE m shifts to SBS k by relaying data via RSUE $n_k \in \mathcal{N}_k$, $\forall k \in \mathcal{K}$ as follows:

$$R^{\mathrm{r}}_{m,n_k,k} = \frac{W_m}{2}\log_2\left(1 + \frac{1}{\Gamma} SINR^{AF}_{m,n_k k}\right), \quad (2)$$

where $SINR^{AF}_{m,n_k,k}$ is SINR in *AF* method of SMUE m to SBS k via RSUE n_k, which is computed as below:

$$SINR^{AF}_{m,n_k,k} = \frac{P_m |h_{m,k}|^2}{\sigma^2} + \frac{P_m P_{n_k}(m) |h_{m,n_k}|^2 |h_{n_k,k}|^2}{\sigma^2\left(P_m |h_{m,n_k}|^2 + P_{n_k}(m)|h_{n_k,k}|^2 + \sigma^2\right)}, \quad (3)$$

where P_m is the maximum power level that can be allocated for SMUE m's when the handover occurs, $P_{n_k}(m)$ is power level of RSUE $n_k \in \mathcal{N}_k$ relaying data of SMUE m. $|h_{m,n_k}|^2$ and $|h_{n_k,k}|^2$ are channel gains from SMUE m to RSUE n_k and from RSUE n_k to SBS k, respectively.

When a SMUE processes its handover scheme, each SMUE needs to choose a relay as by following criteria.

Criteria of a SMUE's relay selection. In the relay selection of each SMUE, a binary variables $\alpha_{m,n_k} \in \{0, 1\}$ is defined to indicate selection a RSUE n_k of SMUE m. When $\alpha_{m,n_k} = 1$, RSUE m is selected by SMUE m; otherwise, $\alpha_{m,n_k} = 0$. Due to each SMUE only selects at most a RSUE at a given time, the below condition has to satisfy:

$$\sum_{\forall n_k \in \mathcal{N}} \alpha_{m,n_k} \leq 1, \forall m \in \mathcal{M}. \quad (4)$$

Moreover, each RSUE can only be served at most a RSUE at a given time, thus

$$\sum_{\forall m \in \mathcal{M}} \alpha_{m,n_k} \leq 1, \forall n_k \in \mathcal{N}. \quad (5)$$

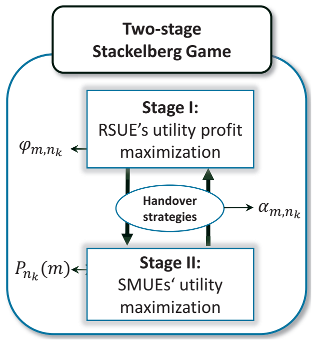

Fig. 2: Determination of optimal handover strategies.

We note that SMUEs that cannot select any RSUE will wait in next time period. Only when SMUE m shifts to SBS k, SMUE m will be processed to choose a RSUE n_k to increase its transmission rate. Moreover, our work only considers SMUEs where the data rate in user relay assisted handover are higher than the data rate in the direct handover ($R^{\mathrm{d}}_{m,k} < R^{\mathrm{r}}_{m,n_k,k}$). In order to improve transmission rate, RSUEs are always considered in SMUEs' cooperative transmissions.

In order to promote assistance from RSUEs to improve data rate of SMUEs, we propose a trading exchange model which is formed based on Stackelberg game model in next section.

III. Stackelberg Game Formulation for Handover Processes

This section expresses a trading exchange model among the SMUEs and RSUEs that are constructed based on two-stage Stackelberg game model as Fig. 2. In stage II, SMUEs are modeled as buyers who have strategies to buy power levels from relay users to maximize their utility function. In stage I, RSUEs as sellers who have pricing-based strategies on each power unit to SMUEs to maximize their profit. Moreover, RSUEs and SMUEs have strategies to match pair RSUE and SMUE to maximize both RSUEs and SMUEs utility functions. Details are discussed in next subsections.

A. RSUE's strategy of game in Stage I

When a RSUE plays a role as a helper for the SMUE's shift process, the RSUE consumes its power to relaying data as in (2), (3). In economic view point, the RSUE has an incentive to earn, the payment which not only covers its forwarding cost but also obtains as much profit as possible. Consequently, when RSUE n_k becomes a relay of SMUE m, it sets a price to maximize its utility function which is addressed as follows (OPT-1):

$$\begin{aligned} \max \quad & U_{n_k}(m) = \mathcal{R}_{n_k}(P_{n_k}) - \mathcal{C}_{n_k}(P_{n_k}) \qquad (6)\\ \text{subject to:} \quad & \\ & 0 \le \zeta_{n_k} \le \varphi_{m,n_k}, \qquad (7)\\ & \text{variables} \quad \{\varphi_{m,n_k}, \forall n, k\}, \end{aligned}$$

where $\mathcal{R}_{n_k}(P_{n_k}) = \varphi_{m,n_k} P_{n_k}(m)$ denotes by revenue of RSUE n_k, $\mathcal{C}_{n_k}(P_{n_k}) = \zeta_{n_k} P_{n_k}(m)$ is cost of RSUE n_k, ζ_{n_k} is the cost per power unit of RSUE n_k for a power unit, φ_{m,n_k} is the price per a power unit of SMUE m that it pays to RSUE n_k, and $P_{n_k}(m)$ is power level of RSUE n_k which is bought by SMUE m. Thus, RSUE n_k has strategies to increase its price which charges to SMUE m to increase profit. But, an increase in profit of the RSUE is dependent on the SMUE' strategy that buys its power level, which is addressed in next section.

B. SMUEs' strategies of game in Stage II.

A SMUE will increase its data rate when it relays via a RSUE. Hence, total data rate of SMUEs can be improved with help from RSUEs, and the service provider can get more benefit from increasing data rate of its users. In order to increase data rate of SMUEs, we find optimal handover strategies of SMUEs in a way that maximize SMUEs' utility function as follows as below:

$$\begin{aligned} \mathbf{U}_{\mathrm{SMUE}} = & \sum_{m\in\mathcal{M}} \sum_{k\in\mathcal{K}} \sum_{n_k\in\mathcal{N}_k} \alpha_{m,n_k} R^r_{m,n_k,k} \\ & - \sum_{m\in\mathcal{M}} \sum_{k\in\mathcal{K}} \sum_{n_k\in\mathcal{N}_k} \alpha_{m,n_k} \varphi_{m,n_k} P_{n_k}(m), \end{aligned} \qquad (8)$$

where the utility function $\mathbf{U}_{\mathrm{SMUE}}$ is defined by total data rate of SMUEs minus total cost of handover strategies using relay scheme.

Thus, given the strategies pricing-based of RSUEs, SMUEs need to find optimal strategies composing of RSUEs selection, and power level $P_{n_k}(m)$ to maximize the following optimization problem (OPT-2):

$$\begin{aligned} \max \quad & \mathbf{U}_{\mathrm{SMUE}} \qquad (9)\\ \text{subject to} \quad & (4), (5),\\ & P_{n_k}(m) \in \mathcal{P}_{n_k} = [0, P^{\max}_{n_k}], \qquad (10)\\ & \alpha_{m,n_k} = \{0,1\}, \qquad (11)\\ \text{variables} \quad & \{P_{n_k}(m), \alpha_{m,n_k}\}, \end{aligned}$$

where, $P^{\max}_{n_k}$ is maximum power level of RSUE n_k can be used. The purpose of the OPT-2 is to find optimal strategies $P_{n_k}(m)$ and α_{m,n_k} to maximize utility function $\mathbf{U}_{\mathrm{SMUE}}$.

IV. Optimal Strategies Analysis of Proposed Game Based on Backward Induction

In this section, we first analyze the strategies of the SMUEs and RSUEs based on backward induction of the game. Second, we find the optimal price strategy φ^*_{m,n_k} and optimal power level $P^*_{n_k}(m)$ of RSUEs and SMUEs, respectively. Finally, we propose a distributed algorithm to optimize user relay selection strategy α^*_{m,n_k} in a combinatorial optimization problem of competition among multiple RSUEs and multiple SMUEs in the game based on matching theory.

A. Backward induction analysis

Since OPT1 is mixed-integer NP-hard problem, we need to transform to a simple problem to solve it easily. From equations (4) and (5), the SMUEs' utility function in (8) can be written as follows:

$$\mathbf{U}_{\text{SMUE}} = \sum_{m\in\mathcal{M}}\sum_{k\in\mathcal{K}}\sum_{n_k\in\mathcal{N}_k} \alpha_{m,n_k}(R^{\text{r}}_{m,n_k,k} - \varphi_{m,n_k}P_{n_k}(m)). \tag{12}$$

Letting $U_m(n_k,k) = R^{\text{r}}_{m,n_k,k} - \varphi_{m,n_k}P_{n_k}(m)$, we see that the optimization problem of the SMUEs's game is a mixed integer problem. As shown in equation (12), utility function $\mathbf{U}_{\text{SMUE}}$ increases as function $U_m(n_k,k)$ grows. Moreover, $U_m(n_k,k)$ is independent of others actions. Thus, this optimization problem can be solved in two linear parts based on backward induction. First of all, given fixed feasible values α_{m,n_k}, an optimal amount of cooperative transmission power $P^*_{n_k}(m)$ is determined to maximize $U_m(n_k,k)$ based on price strategies φ_{m,n_k} from RSUEs. Then, in backward induction, based on $P^*_{n_k}(m)$, we find an optimal price strategies φ^*_{m,n_k} to maximize RSUEs' utility functions. After that, the optimal relay selection α^*_{m,n_k} is decided to maximize the overall utility of both SMUEs and RSUEs.

B. Find optimal power and pricing strategies

Based on backward induction analysis, given fixed feasible value α_{m,n_k}, we find optimal strategies φ^*_{m,n_k} and $P^*_{n_k}(m)$ as follows. First of all, given pricing based strategies φ^*_{m,n_k}, we find optimal power level $P^*_{n_k}(m)$ in below optimization problem:

$$\begin{aligned} &\max \quad U_m(n_k,k) = R^{\text{r}}_{m,n_k,k} - \varphi_{m,n_k}P_{n_k}(m) \qquad (13)\\ &\text{subject to} \quad (10),\\ &\text{variables} \quad \{P_{n_k}(m), \forall m,n,k\}. \end{aligned}$$

The optimal strategy of RSUE m given pricing-based strategy φ_{m,n_k} of RSUE n_k can be found by setting the first derivative $\frac{\partial U_m(n_k,k)}{\partial P_{n_k}(m)} = 0$, as follows:

$$\begin{aligned} &P^*_{n_k}(m)\\ &= \Bigg[-\frac{(C_{m,n_k,k}+2)D_{m,n_k,k}}{2(1+C_{m,n_k,k})}\\ &+\sqrt{\frac{C^2_{m,n_k,k}D^2_{m,n_k,k}}{4(1+C_{m,n_k,k})^2} + \frac{C_{m,n_k,k}D_{m,n_k,k}W_m}{2\ln 2(1+C_{m,n_k,k})}\varphi^{-1}_{m,n_k}}\,\Bigg]^{\mathcal{P}_{n_k}}, \end{aligned} \tag{14}$$

where $[P_{n_k}(m)]^{\mathcal{P}_{n_k}}$ is the projection of $P_{n_k}(m)$ onto the set $\mathcal{P}_{n_k}$; $C_{m,n_k,k} = \frac{P_m|h_{m,n_k}|^2}{\Gamma\sigma^2+P_m|h_{m,k}|^2}$ and $D_{m,n_k,k} = \frac{P_m|h_{m,n_k}|^2+\sigma^2}{|h_{n,k}|^2}$; P_m is fixed power of RSUE m that SMUE takes a fixed power level in shift process.

Based on the pricing-based strategy $P_{n_k}(m)$ of RSUE m, we replace (14) into (6) to find optimal price strategy φ^*_{m,n_k}.

Proposition: Given an optimal power strategy as in (14) and constraint in OPT-1, there exists an optimal price

$$\varphi^*_{m,n_k} = \arg\max_{\{\varphi_{m,n_k}\}} \left(\varphi_{m,n_k} - \zeta_{n_k}\right)P^*_{n_k}(m)(m)\,. \tag{15}$$

Proof: We have $\frac{\partial^2 U_{n_k}(m)}{\partial\varphi^{*2}_{m,n_k}} \le 0$. Hence, utility function U_{n_k} in (15) is concave function [11]. ■

The optimal value φ^*_{m,n_k} can be obtained by taking $\frac{\partial U_{n_k}(m)}{\partial\varphi_{m,n_k}} = 0$. After the optimum power unit price φ^*_{m,n_k} is computed, the optimum power $P^*_{n_k}(m)$ is obtained in (14). Therefore, by replacing φ^*_{m,n_k} and $P^*_{n_k}(m)$ into (6) and (13), the utility values of both RSUE m and RSUE n_k are calculated as follows:

$$U_m(n_k,k) = R^{\text{r}}_{m,n_k,k}(P^*_{n_k}(m)) - \varphi^*_{m,n_k}P^*_{n_k}(m), \tag{16}$$
$$U_{n_k}(m) = (\varphi^*_{m,n_k} - \zeta_{n_k})P^*_{n_k}(m). \tag{17}$$

Therefore, by substituting results in (16) and (17) into OPT-2, we have:

$$\begin{aligned} &\max_{\alpha_{m,n_k}} \quad \mathbf{U}_{\text{SMUEs}}(P^*_{n_k}(m), \varphi^*_{m,n_k}) \qquad (18)\\ &\text{subject to} \quad (4),(5),(11),(16), \text{and } (17). \end{aligned}$$

It should be noted that the SMUEs and RSUEs selfishly and rationally interact in a way that theirs utility are maximized. Therefore, in order to maximize (18), each SMUE m prefers to choose RSUE n_k that gets the highest utility value $U_m(n_k,k)$ as in (16). Contrary to action of the SMUE, the RSUE enables relaying data of a SMUE which maximizes its utility as in (17). Hence, the optimization problem in (13) becomes a NP-hard combinatorial optimization problem which contains mixed strategies among SMUEs and RSUEs. Consequently, we propose a distributed algorithm to optimize strategies of both SMUEs and RSUEs based on matching theorem in next subsection.

C. Distributed algorithm to find optimal handover strategies based on matching theory

Herein we propose a distributed algorithm Alg. 1 which determines optimal strategies α^*_{m,n_k} based on matching theorem to solve OPT-4 in a stable matching [8], [12]. For the relay selection problem, the one-to-one matching theory is applied in which each SMUE will be matched to maximum one RSUE. Formally, we can define the matching game of relay selection problem (μ_{RS}) as follows:

Definition 1: Given two disjoint finite sets of players $\mathcal{N}$ RSUEs and $\mathcal{M}$ SMUEs, a matching game μ_{RS} is defined as a function μ_{RS}: $\mathcal{M} \mapsto \mathcal{N}$ such that:
1, $m = \mu_{\text{RS}}(n_k) \leftrightarrow \mu_{\text{RS}}(m) = n_k$, $n_k \in \mathcal{N}$;
2, $|\mathcal{N}^{\text{matched}}_m| \le 1$ and $|\mathcal{M}^{\text{matched}}_{n_k}| \le 1$;
3, Two preference lists $\Phi^{n_k}_{\text{RS}}$, Φ^m_{RS} over one another, i.e., rank, respectively, the players in $\mathcal{N}$ and $\mathcal{M}$.

The outcome of the matching game is function of the user association μ. If SMUE m is matched to RSUE n_k ($n_k = \mu_{\text{RS}}(m)$), then SMUE m is also matched to RSUE n_k ($m = \mu_{\text{RS}}(n_k)$). The condition $|\mathcal{M}^{\text{matched}}_{n_k}| \le 1$ is restriction at most

Algorithm 1 : Matching algorithm for relay selection (MA-RS)

* **Input:**
1: $\mathcal{N}$, $\mathcal{M}$, $\mathcal{M}_{n_k}^{\text{matched}} = \emptyset$, $\mathcal{M}_{n_k}^{\text{req}} = \emptyset$, $\forall m, n, k$;
* **Discovery and utility computation:**
• Each SMUE m do:
2: Detects $\mathcal{N}_m$ and computes $\phi_{\text{RS}}^{m}(n_k)$ from (20);
3: $\Phi_{\text{RS}}^{m} \leftarrow \Phi_{\text{RS}}^{m} \cup \phi_{\text{RS}}^{m}(n_k)$ with descended utility list;
• Each RSUE n_k do:
4: $\mathcal{M}_{n_k} \leftarrow \mathcal{M}_{n_k} \cup n_k$ based on SMUEs' detection;
5: Computes $\phi_{\text{RS}}^{n_k}(m)$ from (22);
* **Swap-matching to find stable matching μ_{RS}^{*}**
repeat
• Each SMUE m do:
5: if SMUE m receives RTD from RSUE n_k then $\Phi_{\text{RS}}^{m} = \emptyset$;
6: if SMUE m receives RTR from RSUE n_k then
10: removes $\phi_{\text{RS}}^{m}(n_k)$ in Φ_{RS}^{m};
7: if $\Phi_{\text{RS}}^{m} \neq \emptyset$ then sends a request to RSUE n_k in $\Phi_{\text{RS}}^{m}(1,1)$;
8: end
9: else sends request to RSUE n_k in $\Phi_{\text{RS}}^{m}(1,1)$;
10: end
• Each RSUE n_k do:
11: update $\mathcal{M}_{n_k}^{\text{req}}$ and sorts $\Phi_{\text{RS}}^{n_k}$ by descending utilities list;
12: if $|\mathcal{M}_{n_k}^{\text{matched}}| = 0$
13: $\mathcal{M}_{n_k}^{\text{matched}} = \mathcal{M}_{n_k}^{\text{matched}} \cup \{m | m \in \Phi_{\text{RS}}^{n_k}(1,1)$;
14: $\mathcal{M}_{n_k}^{\text{reject}} = \mathcal{M}_{n_k}^{\text{req}} \setminus \mathcal{M}_{n_k}^{\text{matched}}$;
15: else
16: $\mathcal{M}_{n_k}^{\text{reject}} = \mathcal{M}_{n_k}^{\text{req}}$;
17: end
18: sends RTR to m, $\forall m \in \mathcal{M}_{n_k}^{\text{reject}}$;
19: sends RTD to m and updates $\alpha_{m,n_k} = 1$, $\forall m \in \mathcal{M}_{n_k}^{\text{matched}}$;
20: **until**
21: $\Phi_{\text{RS}}^{m} = \emptyset, \forall m \in \mathcal{M}$;
* **Output**: Convergence to a stable matching μ_{RS}^{*} and optimal vector α^{*}.

one SMUE matched to each RSUE. In order to apply matching theorem to find optimal relay selections of OPT-4, we define preference lists Φ^{m} as vector of utilities value of SMUE m as follows:

$$\Phi_{\text{RS}}^{m} = [\phi_{\text{RS}}^{m}(n_k)]_{1\times|\mathcal{N}_m|}, \forall m \in \mathcal{M}, \tag{19}$$

in which

$$\phi_{\text{RS}}^{m}(n_k) = U_m(n_k, k), \tag{20}$$

where $\mathcal{N}_m$ is a set of RSUE n_k can relay SMUE m's data, $\phi_{\text{RS}}^{m}(n_k)$ is the utility value of SMUE m when it establishes RSUE n_k as a relay, $U_m(n_k, k)$ is defined in (18).

At RSUEs side, each RSUE n_k also constructs its preference list $\Phi_{\text{RS}}^{n_k}$ which captures utility values as in (17) from requests relaying data of SMUEs as follows:

$$\Phi_{\text{RS}}^{n_k} = [\phi_{\text{RS}}^{n_k}(m)]_{1\times|\mathcal{M}_{n_k}|}, \forall n_k \in \mathcal{N}, \tag{21}$$

in which

$$\phi_{\text{RS}}^{n_k}(m) = U_{n_k}(m). \tag{22}$$

where $\mathcal{M}_{n_k}$ is a set of SMUEs that requests relay data via RSUE n_k, $\phi_{\text{RS}}^{n_k}(m)$ is the utility value of RSUE n_k when establishes a relay scheme with SMUE m, $U_{n_k}(m)$ is computed in (17).

We next explain the operation of Alg. 1.

In Alg. 1, first of all, SMUEs using broadcast messages to detect the nearby RSUEs and compute utilities values (lines 2,3). At RSUEs side, they also compute their utility values (lines 4,5). The matching algorithm is established in the Swap-matching to find stable matching μ_{RS}. Based on utility functions, each SMUE m tries to match with a relay user RSUE n_k that have highest utility value in its preference list (lines 7,9). At RSUEs side, each RSUE n_k try to enable relaying data of SMUE m that brings its highest utility value (lines 13). SMUEs that cannot be matched to RSUE n_k will send a request to delete (RTD) to remove RSUE n_k at preference list of SMUEs (lines 5,19). Each SMUE m that matched to RSUE n_k will send a request to delete database at SMUE m. Each pair matched RSUE-SMUE updates optimal value $\alpha_{m,n_k} = 1$. The matching algorithm will finish when SMUEs' preference lists are empty which converges to a stable matching μ_{RS}^{*}. Convergence of our algorithm is proved based on [12].

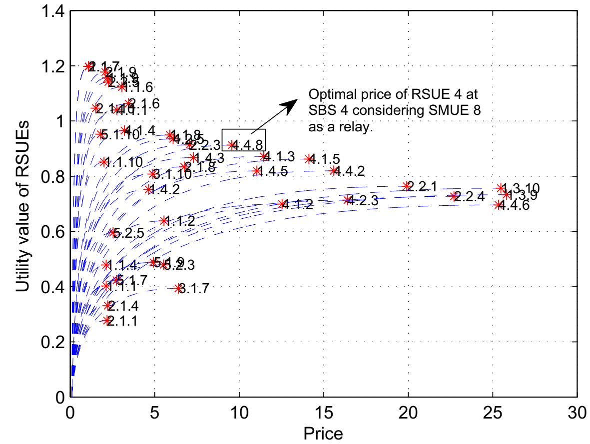

Fig. 3: The maximum expected utility of RSUEs depend on discount factor β and initial states

Finally, the optimal strategies α_{m,n_k}^{*} are found. Substituting optimal values α_{m,n_k}^{*} into (18) and (6), a maximum value of utility U_{SMUE}^{*} and $U_{n_k}^{*}$ are computed, respectively.

V. Numerical results and discussions

In this section we present our simulator with Matlab to evaluate the performance of both multiple SMUEs and RSUEs strategies. We consider an outdoor environment where the MBS and 4 SBSs are located as in Fig. 1. Moreover, some parameters are installed as follows: $P_m = 100mW$, $P_{n_k} = 100mW$, $W_m = 1$, $\sigma = -105$ dBm, $\Gamma = 1$, flat price $\zeta_{n_k} = 0.5$, and the propagation loss factor = 3.5, $\forall m, n, k$. At initial step, there are 4 RSUEs randomly distributed within a radius of $170m$ from SBSs. The AF scheme is installed at each RSUE. Additionally, there 10 SMUEs randomly distributed within a range from $180m$ to $220m$ which get low SINR from SBSs in conventional direct handover. It should be noted that, the coverages of SBSs can overlap with others. Hence, each SMUE can select its handover strategies from a set of candidate SBSs and RSUEs to improve data connection rate.

In Fig. 3, we determine the optimal price strategies corresponding to each pair SMUE-RSUE that can be formed based on (16) and (17). Based on strategies of pricing and power level, SMUEs and RSUEs build their preference lists as in (19), (21). After that, we optimize strategies to find

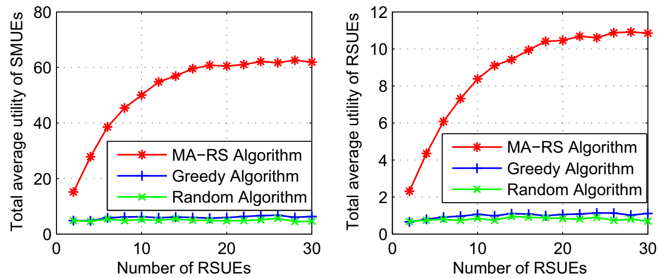

Fig. 4: Average sum rate of SMUEs and RSUEs given M = 10 SMUEs

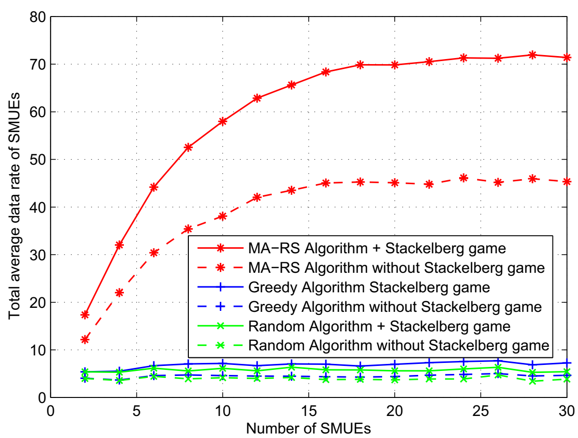

Fig. 5: Average utility value of SMUEs and RSUE given M = 10 SMUEs

best strategies relay selection based on Alg. 1. Depending on each network configuration states, we implement handover strategies with Greedy Algorithm and Random Algorithm. In the Greedy algorithm, a SMUE always chooses a RSUE that brings its highest utility, and RSUE chooses a SMUE which brings highest value. In the Random Algorithm, a SMUE randomly selects a RSUE and a RSUE randomly selects a SMUE. In the Fig. 4, clearly, when the number of RSUE in each SBS is increased from 2 to 18 RSUEs, the total average utility of SMUEs increases. At RSUEs side, they also get optimal handover strategies of pricing, power level and relay selection which maximize their utility values.

Next, we compare the results of the proposed scheme (MA-RS algorithm+Stackelberg game) with the MA-RS without Stackelberg game, Stackelberg game with Greedy Algorithm selecting relay users, greedy algorithm without Stackelberg game, Stackelberg game with random algorithm that randomly SMUEs choose relay users, and SMUEs randomly choose RSUE without game. In Fig. 5, we can see that our proposal with Stackelberg game combined with MA-RS algorithm is the best scheme which archived the highest total data connection in stable matching of handover strategies. Moreover, simulation results show that the average total data rate in our proposal is 60% percents greater than conventional direct handover.

VI. Conclusion

In this paper, we studied the relay-aided cooperative model to support load-sharing in uplink two-tier cellular networks. In order to mitigate SINR degradation problem in conventional direct handover, users in heavily loaded macrocell are shifted to lightly loaded smallcells with the assistance of relay users. The two-stages Stackelberg game model proposed to optimize strategies of users. By solving this game, relay users had pricing-based strategies per each power unit to heavily loaded macrocell users to maximize theirs revenue utility function. Moreover, users in heavily loaded macrocell also optimized strategies of power levels to buy from relay users to maximize their utility function. Furthermore, optimal handover strategies are determined based on matching theory based on the distributed algorithm. Simulation results shown, our proposal can improve the total rate average value in handover strategies up to 60% than conventional direct handover.

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