On Relay Placement Schemes for Multi-cell LTE-A System Under Co-channel Interference

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***Abstract*—Due to the frequency reuse, LTE-A is interference limited system, the small rates can only been obtained by cell-edge users. Cooperative communication through using relays is an efficient approach to resolve this problem. In this paper, We proposed a dynamic relay placement scheme to maximize either the total cell capacity or the total cell-edge user capacity in a LTE-A network under co-channel interference. Two strategies, Amplify-and-Forward (AF) and Decode-and-Forward (DF) for cell-edge user are compared. The simulation results show adding relays and optimizing relays position in the cell can significantly increase the capacity for the cell-edge users. The performance of AF strategy is better than the performance of the DF strategy for cell-edge users. The result of simulations prove that this approach can ensure a fair capacity distribution over the cell.**

***Index Terms*—Cooperative communication, relay placement, amplify-and-forward, decode-and-forward, LTE-A .**

I. Introduction

LTE-Advanced (LTE-A), also known as LTE Release 10, has been a candidate of 4G (The 4th Generation Mobile Communication) wireless network standards by ITU (International Telecommunication Union) [1]. In contrast to LTE, LTE-A offers higher peak rates, higher throughput and larger coverage. In order to increase the spectrum efficiency and overall capacity, frequency reuse technique is normally adopted in LTE-A. LTE-A adopts a reuse-1 OFDMA-based access scheme, thus offering higher overall cell rate, especially for cell-centre users (CCUs) rate. However, cell-edge users (CEUs) performance are degraded obviously due to the co-interference. A variety of approaches have been suggested to overcome the co-channel interference and improve the performance of the edge users. Relaying communication obtained a lot of research attention because it can not only enhance the capacity of cell-edge users but also improve the performance of the whole cellular network. It has been accepted as a key technique of LTE-A [1]. Relay stations (RSs) can enhance the link strength between e-Node B (eNB) and edge-user equipment, thus increasing the link capacity and reliability.

In [2], Cover and El Gamal first proposed the ideas of the cooperative communication based information theoretic properties of the relay channel. From then, cooperative communication has attracted many attentions of researchers due to improving the spectral efficiency of each user. In general, the relay stations are placed in the communication network, where they overhear the transmitted data by eNB, then cooperate with it to forward the message to cell-edge users experiencing large channel fading with the eNB. Amplify-and-Forward (AF) and Decode-and-Forward (DF) are the two main forwarding schemes proposed several different cooperative protocols in wireless network by J. Laneman, D. Tse and G. Wornell in [3]. For AF transmission, the relay receives the data from eNB, then amplifies and retransmits it to the UE; for DF transmission, the data are decoded and re-transmitted to the UE by RS.

In the LTE-A network, the placement problem of the relay node is a critical issue. Researchers have provided many schemes in literatures. In [4], the authors studied the optimal placement problem of a given number of relays in WLAN, and proposed an efficient algorithm based on Lagrangian relaxation with sub-gradient iteration to maximizing the network throughput.In [5], two types of RSs, fixed RSs (FRSs) and nomadic RSs (NRSs), have been studied for relaying data transmission between the BS and SSs, the RS placement and bandwidth allocation are jointly considered for the capacity maximization. In [6], a mathematical model of the users traffic demand and cover the request service area is introduced, where the objective function is to minimize the number of relays under a WiMAX network. In [7], the authors studied a general cooperative cellular network, where the subscribers cooperate and relay information to each other to maximize the sum of network capacity. An efficient algorithm was proposed to determine which node should act as a relay, which relay strategy should be used (AF or DF) and which frequency should be used for relaying. In [8], the optimal RS placement about coverage extension in an LTE-A network has been studied. In [9], the authors studied the problem of relay placement and proposed an optimization framework to maximize total cell capacity or total cell-edge capacity in a LTE-A.

In this paper, we consider an LTE-Advanced relay enhanced cooperative cellular network, where the main objective is the optimal placement of a given number of RSs in a certain cell in order to maximize either the total cell capacity or the cell-edge capacity to ensure a fair capacity distribution over the cell. The effect of inter-cell interference as well as intra-cell interference are considered between the relay stations and the eNB. The rest of the paper is organized as follows. Section II describes our system model. Section III present the problem formulation and the description of the simulation setups. Section IV offers

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the simulation results. Finally, Section V concludes this paper.

II. System Model

In this section, we consider a single-tier cellular network system model as Fig.1. This is a typical 7-cell model, where $\mathcal{J}$ denote the set of indices of the 7 eNB, $\mathcal{J} = \{0, 1...j, ...6\}$. We assume there are N UEs with an arbitrary geographical distribute in the centre cell, where $\mathcal{N}$ denote the set of indices of UEs, $\mathcal{N} = \{1, 2..., n, ...N\}$. UEs are classified into either cell-centre or cell-edge UEs according to a threshold received SINR in a cell. We use the $\mathcal{N}_{centre}$ and $\mathcal{N}_{edge}$ denote the sets of cell-centre and cell-edge UEs, respectively. We assume cell-centre UEs communicate with eNB through direction link, cell-edge UEs transmit message with eNB through RSs.

Furthermore, L denote a given number of RSs in the each cell and distributed uniformly on a circle with equal angles in each of the adjacent cells. A given number and geographical distribution of candidate positions (CPs), which are identified to be suitable to placing RSs after site planing. $\mathcal{M} = \{1, 2..., m...M\}$ is the set of indices of CPs in the centre cell. where $\mathcal{M}_A = \{1, 2...m..L\}$ is the set of RSs. The RSs use half-duplex relaying [3] and transmission procedure is completed over two timeslots. In the first timeslot, the eNB transmits the data to all UEs and the relay overhear the transmitted data to cell-edge users and process this data. In the second timeslot the relay retransmit the data processed to their cell-edge users, and the eNB transmit its data all users in the time. In the two timeslots, eNB reuse the resource blocks (RBs) which assigned to the RS-UE links to transmit data to the cell-centre users for increasing the total capacity, this induces intra-cell interference. The relaying strategy is fixed AF or fixed DF [3] according to rate required by cell-edge UEs. In this paper we compared the performance of the two strategies for cell-edge users.

In OFDMA-based 4G wireless systems, co-channel interference is critical issue due to the full frequency reuse for increasing the total capacity, i.e. the frequency reuse factor is 1. Co-channel interference include the inter-interference from the adjacent cell and intra-interference from the same cell. For simplicity, we assume no power control is implemented, where P_e and P_r denote the total transmitting power of eNBs and of RSs, respectively.

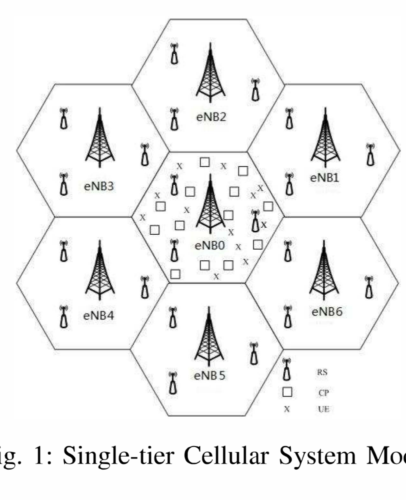

Fig. 1: Single-tier Cellular System Model

III. Problem Formulation

Several decision variables are assumed in the rest of this paper [5]: $X_m = 1$ if RS is placed at CPm; $X_m = 0$ otherwise. According to [3], in each timeslot the maximum achievable rate between input and output is given by

$$r_D = \log(1 + SINR_{eNB,D}), \tag{1}$$

in (1), D denote UEs or RSs connected directly to the eNB. In the two timeslots, for the cell-edge user UEn , the maximum average mutual information have different formula according to relay strategy

$$r^{AF}_{m,n} = \frac{1}{2}\log\left(\begin{array}{l} 1 + SINR_{eNB,UEn} + \\ f(SINR_{eNB,RSm}, SINR_{RSm,UEn} \end{array}\right) \tag{2}$$

where

$$f(x, y) := \frac{xy}{x + y + 1}. \tag{3}$$

$$r^{DF}_{m,n} = \frac{1}{2}\min\left\{\begin{array}{l} \log(1 + SINR_{eNB,RSm}), \\ \log(1 + SINR_{eNB,UEn} + SINR_{RSm,UEn}) \end{array}\right\}. \tag{4}$$

(2) and (4) are maximum achievable rate for cell-edge UEs relayed by RS placed at CPm using AF and DF strategy in two timeslots, respectively.

A. Interference and Channel Model

We just only consider the large scale fading model (path loss and shadow fading), and neglect the small scale fading (frequency selective fading and time selcetive fading) because the object that we are handling is a network planning problem. Then the desired signals power and interference power from the adjacent eNBs on each RB for a receiving node can be denoted by:

$$R^{eNB}_{j,x} = \begin{cases} P_{eNB} - PL_{j,x}, j = 0 \\ \\ P_{eNB} - PL_{j,x}, j \neq 0 \end{cases}, x \in \mathcal{N} \bigcup \mathcal{M}, j \in \mathcal{J} \tag{5}$$

where $R^{eNB}_{j,x}$ is the receiving signal power ($j = 0$) or interference power ($j \neq 0$) on the x^{th} node (UEs or RSm). P_{eNB} is the power of eNBs per RB, here, $P_{eNB} = \frac{P_e}{C}$, C is number of available RBs. $PL_{j,x}$ is the pathloss of power between the j^{th} eNB and the x^{th}. All power are expressed in decibels (dB). Similary, we can calculate the receiving power and interference power from the RSs on each RB for cell-edge user:

$$R^{RS}_{j,m,n} = \begin{cases} \frac{1}{L}(P_{RS} - PL^{j}_{m,n}), j = 0, m \in \mathcal{M} \\ \\ \frac{1}{L}(P_{RS} - PL^{j}_{m,n}), j \neq 0, m \in \mathcal{M_A} \end{cases}, n \in \mathcal{N}, j \in \mathcal{J} \tag{6}$$

where $R^{RS}_{j,m,n}$ is the average receiving power ($j = 0$) or interference power ($j \neq 0$) on UEn from the RSm placed in the j^{th} cell, $PL^{j}_{m,n}$ is the pathloss of the link between dell-edge user (UEn) and RSm in the j^{th} cell. P_{RS} is the transmitting power of RSs served cell-edge user. All power are expressed in decibels (dB). $\frac{1}{L}$ is the probability of an active RB assigned to a RS-UE link in the cells [10]. For simplicity, we assume that there are L RSs placed in the fixed position in the adjacent cells, however, the position of the RSs in the centre cell can change dynamic. We consider three different placement schemes of the RSs in the cell in following section :

B. Scheme 1. No Relays

In this case, no relay is placed in the a network, so all users are connected to the eNB directly. We can calculate the maximum achievable rate for the n^{th} UE on single RB by:

$$r_n = W \log(1 + SINR_{eNB,UEn}), \tag{7}$$

where

$$SINR_{eNB,UEn} = \frac{R_{0,n}^{eNB}}{N_0 W + \Sigma_{j=1}^{6} R_{j,n}^{eNB}}, \tag{8}$$

W denotes the bandwidth of a single RS and N_0 denotes the power spectral density of noise. Without loss of generality, we assume that each user is assigned to one RB only.

C. Scheme 2: Fixed and Uniform Relay Position

In this case, a network with the L RS in the center and adjacent cell, where the RS are placed in each cell fixed at equal angles on a circle of radius $0.7R$, is considered, as shown Fig. 1. We can distinguish the UEs which is cell-center or cell-edge UEs by setting a threshold corresponding to a spectral efficiency of 0.033bps/Hz [11], and the relay serve the edge UEs only .

For the cell-edge UEs, the maximum achievable rate of the n^{th} edge UE served by RS_m is calculated by:

$$r_{m,n}^{DF} = \frac{1}{2} min \left\{ \begin{array}{l} \log(1 + SINR_{eNB,RSm}), \\ \log(1 + SINR_{eNB,UEn} + SINR_{RSm,UEn}) \end{array} \right\}, \tag{9}$$

$$r_{m,n}^{AF} = \frac{1}{2} \log \left(\begin{array}{l} 1 + SINR_{eNB,UEn} + \\ f(SINR_{eNB,RSm}, SINR_{RSm,UEn} \end{array} \right). \tag{10}$$

Formula(9) and (10) are maximum achievable rate under DF and AF, respectively, where

$$SINR_{eNB,UEn} = \frac{R_{0,n}^{eNB}}{N_0 W + \Sigma_{j=1}^{6} R_{j,n}^{eNB}}, \tag{11}$$

$$SINR_{eNB,RSm} = \frac{R_{0,m}^{eNB}}{N_0 W + \Sigma_{j=1}^{6} R_{j,m}^{eNB}}, \tag{12}$$

$$SINR_{RSm,UEn} = \frac{R_{0,m,n}^{Rs}}{N_0 W + \Sigma_{j=1}^{6} R_{j,n}^{eNB} + \frac{1}{L} \Sigma_{j=1}^{6} \Sigma_{m=1}^{L} R_{j,m,n}^{Rs}}. \tag{13}$$

in (13), the summation in the second term of the denominator includes intra-cell interference from the eNB_0 due to reusing of RBs in the second timeslot, and the third term represents the inter-cell interference from the relays of adjacent cells.

For the cell-center UEs, we can calculate maximum achievable rate of the n^{th} UE through getting rate of the first and second timeslot, respectively. In the first timeslot the maximum achievable rate is:

$$r_{1n} = \frac{1}{2} log(1 + SINR_{eNB,UEn}), \tag{14}$$

where $SINR_{eNB,UEn}$ can be obtain from formula (8). In the second timeslot the cell-center UE can be calculated by:

$$r_{2n} = \frac{1}{2} log(1 + SINR_{eNB,UEn}), \tag{15}$$

where

$$\begin{aligned} SINR_{eNB,UEn} = R_{0,n}^{eNB} / (N_0 W + \sum_{j=1}^{6} R_{j,n}^{eNB} + \\ \frac{1}{L} \sum_{j=1}^{6} \sum_{m=1}^{L} R_{j,m,n}^{RS} + \frac{1}{L} \sum_{m=1}^{L} R_{0,m,n}^{RS}). \end{aligned} \tag{16}$$

The second and third terms in the denominator represent the average inter-cell interference from the eNBs and RSs in the adjacent cells, respectively. The fourth term represents the average intra-cell interference. As [12], the total achievable rate over the two timeslots can been calculated by:

$$r_n = r_{1n} + r_{2n} \tag{17}$$

IV. Scheme 3: Dynamic Optimal Relay Positions

In this case, there are L RSs are placed at the L candidate positions (CPs) in the center cell, however, in the adjacent cell the L RSs are placed uniformly on a circle of $0.7R$. The achievable rate equations in the scheme are the same as scheme 2, but (16) need to be changed:

$$\begin{aligned} SINR_{eNB,UEn} = R_{0,n}^{eNB} / (N_0 W + \sum_{j=1}^{6} R_{j,n}^{eNB} + \\ \frac{1}{L} \sum_{j=1}^{6} \sum_{m=1}^{L} R_{j,m,n}^{RS} + \frac{1}{L} \sum_{m=1}^{M} X_m R_{0,m,n}^{RS}), \end{aligned} \tag{18}$$

where the value of X_m is 0 or 1, $X_m = 1$ means the RS are placed at the the CPs, otherwise $X_m = 0$.

According to criterion of maximum edge rate or total rate, the optimal position of RSs can be calculated from following equations:

$$\max_{X,Y} \sum_{\substack{n \in \mathcal{N}_{edge} \\ m \in \mathcal{M}}} Y_{m,n} r_{m,n}, \tag{19}$$

$$\max_{X,Y} \left(\sum_{n \in \mathcal{N}_{centre}} r_n + \sum_{\substack{n \in \mathcal{N}_{edge} \\ m \in \mathcal{M}}} Y_{m,n} r_{m,n} \right), \tag{20}$$

s.t.

$$\sum_{m=1}^{M} Y_{m,n} = 1, n \in \mathcal{N}_{edge}, m \in \mathcal{M}, \tag{21}$$

$$Y_{m,n} \leq X_M, n \in \mathcal{N}_{edge}, m \in \mathcal{M}, \tag{22}$$

$$\sum_{m=1}^{M} X_m = L, m \in \mathcal{M}, \tag{23}$$

$$X_m, Y_{m,n} \in 0, 1. \tag{24}$$

in (19), the objective function is maximization of the total edge capacity, while (20) is the maximization of the total capacity. (21)-(24) are constraint conditions, (21) ensures every edge user is assigned to an RS, (22) ensures that an RS can be assigned to a edge user just only it is placed at CPs, (23) means only L position are selected from all CPs, (24) means that the decision variables are binary. From the above, the problem is maximization non-linear integer problem (CMNIP).

V. Simulation Results

In this section, the performance of AF and DF strategies for edge UE are compared. Some assumption are adopted :

$$r \sim U(35m, R) \ and \ \theta \sim \ U(0, 2\pi) \qquad (25)$$

(25) represents UEs are uniformly distributed in the central cell, where r is the distance between eNB and UE, R is the radius of the cell, $U(a, b)$ denotes uniform distribution between a and b , θ is the horizontal angle between eNB and UE, according to [13], R is 500m and the minimum distance between eNB and UEs is 35m;

$$r \sim U(0.6R, 0.8R) \ and \ \theta \sim \ U(0, 2\pi) \qquad (26)$$

30 CPS are uniformly distributed in the center cell according to (26), in the adjacent cell, the RSs are placed at equal angles on a circle of radius as Fig. 1.

In addition, we use Winner II channel model to obtain the path losses of the links. The eNB-UE, eNB-RS and RS-UE link are assumed to be macro-cell link, LOS feeder link and micro-cell link according to [14], respectively. Some other base parameters for simulation are: eNB transmit power is 46 dBm, the transmit power of RS is 30 dBm, N_0 is -174 dBm/Hz, Bandwidth per RB is 180KHz. Exhaustive search has been used to obtain solution for this problem. We just show the results for the case of the maximization cell-edge rate.

Fig. 2 represents the rates of 50 users randomly placed in the center-cell; Fig. 3 is the rates of the edge users; Fig. 4 and Fig. 5 compare the rates of the center-users under no relays, fixed relays and optimal relays in the AF and DF schemes, respectively. Due to co-channel interference using relays, we note that the rates of center users in the center cell are generally decreased. However, the rates of edge users have obviously increased as Fig.6 and Fig.7 due to the use of relays and Optimize the placement of relays. Compare Fig. 6 and Fig. 7, we can see the performance of the AF strategy is better than the performance of the DF strategy. So we suggest using AF strategy for the edge users to achieve maximum edge users rate. Fig. 8 is the Sum rates of cell-center users of no relays, fixed relays, optimal relays with DF and AF schemes. In Fig. 8, the performance of the fixed relays is the worst, for the center users, the sum rates of the DF strategy is better than the AF strategy. Fig. 9 is the sum rates of cell-edge users of no relays, fixed relays, optimal relays with DF and AF schemes, Obviously, AF strategy can achieve maximum rate for edge users through optimal relay placement.

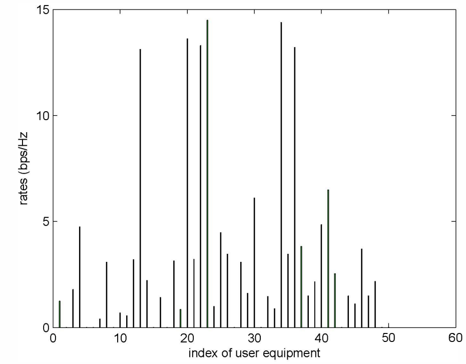

Fig. 2: Rates of all users in the centra-cell

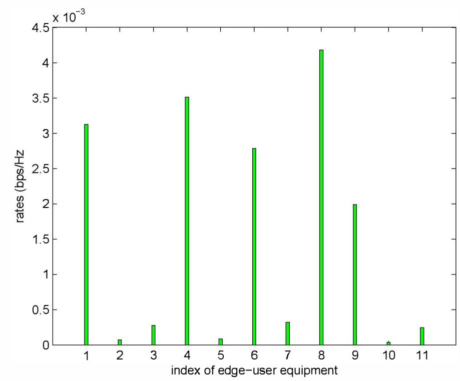

Fig. 3: Rates of cell-edge users in the centra-cell

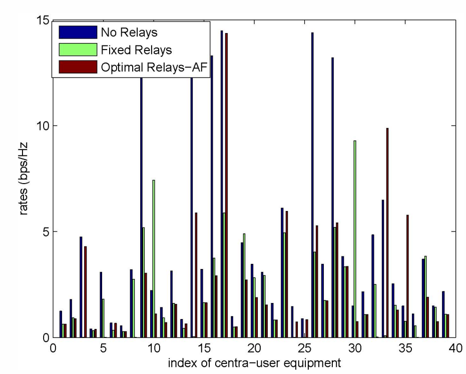

Fig. 4: Rates of cell-center users with AF scheme

VI. Conclusion

In this paper, the relay placement problem about LTE-A has been studied, where the inter-cell and intra-cell interference are both considered. Two strategies (AF and DF) are adopted to optimize the relay placement position for maximizing the total cell capacity or total cell-edge capacity. The simulation results show adding relays and optimizing relays position in the cell can significantly increase the capacity for the cell-edge users. The performance of AF strategy is better than the performance of the DF strategy for cell-edge users. Simulations show the approach's effectiveness and fairness.

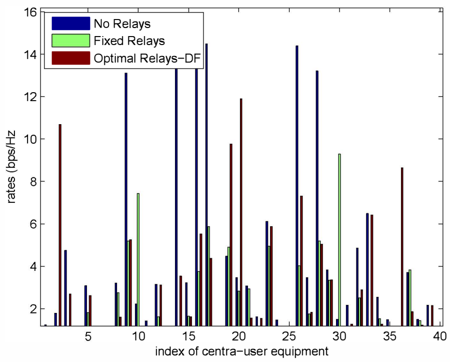

Fig. 5: Rates of cell-center users with DF scheme

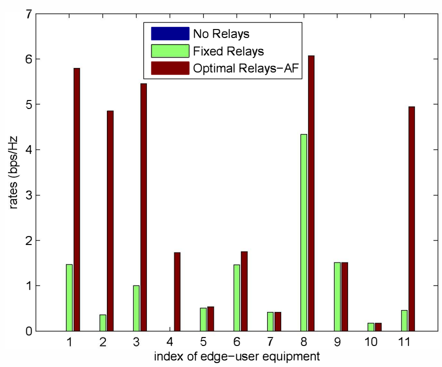

Fig. 6: Rates of cell-edge users with AF scheme

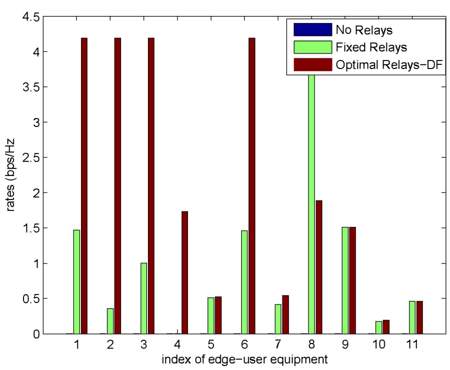

Fig. 7: Rates of cell-edge users with DF scheme

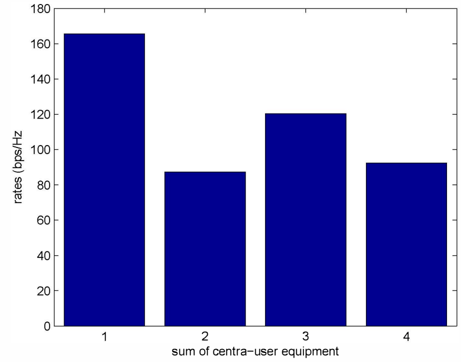

Fig. 8: Sum rates of cell-center users of no relays, fixed relays, optimal relays with DF and AF schemes

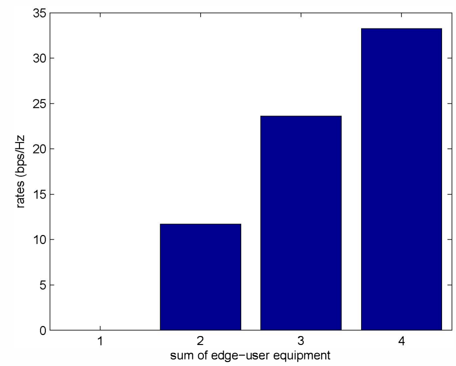

Fig. 9: Sum rates of cell-edge users of no relays, fixed relays, optimal relays with DF and AF schemes

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