Load Balancing for D2D-Based Relay Communications in Heterogeneous Network

Zhuo Chen, Hongyi Zhao, Yang Cao, and Tao Jiang
School of Electronics Information and Communications
Huazhong University of Science and Technology, Wuhan, 430074, P. R. China
Email: Tao.Jiang@ieee.org, chenzhuo2007@hust.edu.cn, zhaohongyi@hust.edu.cn, ycao@hust.edu.cn

***Abstract*— To increase the number of accommodated users in the cellular heterogeneous network (HetNet), we propose an energy efficient load balancing strategy for device-to-device (D2D) based relay communications. In a HetNet, user could sent data to an adjacent uncongested femtocell through the D2D-based relay communications rather than wait for the response from the congested macrocell. Specifically, the proposed strategy manages resources by taking into account both the cross-tier and the co-tier interference, and solves the maximum transmission rate problem based on D2D communications in heterogeneous network. Simulation results show that, with the guarantee of the performance of the pre-existing users, the heterogeneous network can accommodate more users and eventually achieve a higher throughput and better energy efficiency, thus the performance is significantly improved.**

I. INTRODUCTION

Wireless communication networks have always been in continuous evaluation aiming at satisfying the ongoing demand for more system capacity and higher data rates. But it seems cannot catch up with the explosive demand of access brought by the so-called smart devices, even before the turned up of the Internet-of-Things (IoT), which is expected to be two orders of magnitudes larger than the number of traditional consumers. This ends up to the congestion of the tradition cellular base stations (BSs) designed nearly one decade ago for serving areas with large radius, especially containing campus, dense office premises or large business districts. When it happens to come up with some business or festival celebrations, adding communication vehicles turns to be the only solution. Accommodating more users and improving the performance of the overall network based on existing network architecture while meeting the quality-of-service (QoS) of the pre-existing users become the primary requirements [1]. Thus the next generation mobile communication network (5G) needs to have a flexible resource allocation mechanism to accommodate more users while guaranteeing the performance of the pre-existing users.

Thereupon, based on the spectrum reusing, the dense heterogeneous networks (HetNets) [2] and cognitive radio (CR) [3][4] have been proposed to meet the need of more access points and decreasing the cost of deploying new infrastructures. Heterogeneous networks are networks deployed with a traditional macrocell, with a high performance macrocell base station (MBS) covering one or two kilometers, coupled with several smaller cells named femtocell, picocell or small cell. The small cells are usually served by a low power base station (LPBS). Here we take the femtocell for example. A femtocell usually reuses part of the whole available spectrum of the macrocell. As for which part, it should be determined by the interferences caused to and from the macrocell users (MUs) and other femtocell users (FUs). To maintain the interferences from each other below a certain level, the coverage radius of the femtocell base stations (FBSs) are usually limited to a corresponding size. Thus the spectrum reuse factor will increase in the heterogeneous network, bringing much more access points for the users covered by the macrocell. A number of technical studies associated with various aspects of femtocells deployments based on cellular technology have been proposed considering operations, administration, and management (OAM) and self organizing network (SON) protocols, network architecture, local IP access (LIPA), access (open, closed, and hybrid), and interference management. However, due to the limited area served by the low power FBS, some macrocell users cannot connect to the core network through the congested MBS even they are just next to the edge of an uncongested femtocell not quite far away.

Meanwhile, device-to-device (D2D) communication [5]-[9] was proposed as a new way for data transmission which refers to the direct communication between two end devices in proximity in the licensed cellular band with limited BS involvement. In D2D communication, data would be transmitted directly between two devices rather than relayed by the BS, thus relieves the BS from some intra-cell data transmission. The short range direct D2D communication benefits the whole network from the aspects as follows [10]:

Lower complexity and communication delays: Based on the proximity communications within short range using only one-hop, the D2D communications can build up with simpler infrastructure, resulting in lower complexity and communication delays.

Lower power consumptions: Direct communications between adjacent devices have lower path loss, thus the predetermined signal to interference plus noise ratio (SINR) can be reached with high channel gain at a lower transmitting power.

This work was supported in part by the Major State Basic Research Development Program of China (973 Program) with Grant number 2013CB329006, Joint Specialized Research Fund for the Doctoral Program of Higher Education (SRFDP) and Research Grants Council Earmarked Research Grants (RGC ERG) with Grant number 20130142140002, and the Independent Innovation Research Fund of Huazhong University of Science and Technology with Grant number 2014QNRC008.

This contributes to a longer lifetime to the devices driven by the battery as the energy efficiency is improved.

Higher throughput: Benefit from the high channel gain brought by short distance, data between the transmitter and the receiver in the D2D communication is usually transmitted at a high rate, even under a lower transmitting power compared to the conventional communication mode.

Higher spectral efficiency and reuse factor: With proper resource allocation and interference management, the cellular users (the macrocell users and the femtocell users) can share the same spectrum with more than one D2D pair simultaneously.

Improve the quality of experience (QoE) of cell-edge users: As the whole process of D2D communication should be under the supervision of the BS, a device can establish a D2D link to act as a relay between a cell-edge user and the BS to meet the data rate requirement without constructing new infrastructure or act as a relay between an FBS and an MU which is out of the coverage of the FBS when the MBS is congested.

In the context of D2D communication, the interference and spectrum resource management become crucial issues to satisfy the QoS requirements of traditional cellular users and the D2D pairs in the network. An interference management scheme from the perspective of a D2D pair in a MIMO system with M MUs and only one D2D pair has been proposed in [13] to increase the system capacity. A scheme that using dedicated relay nodes to set up D2D communication to relieve intra-cell data transmission from the eNB in [16]. The transmitting power decision and resources partition in multi-tier network have been studied in [17]-[19] considering only one MU coupled with multiple D2D pairs or multiple FUs coupled with only one D2D pair.

In this paper, we propose an uplink spectrum resource scheduling strategy for load balancing with D2D-based relay communications (D2DRC) in a three-tier heterogeneous network to mitigate the interference between all the users working on the same frequency band simultaneously. We aim at increasing the number of accommodated MUs with fair capacity usage of the femtocells while meeting the SINR requirement when the MBS is congested and eventually achieve a higher throughput and better energy efficiency. With the interactions of signal receivers (SRs, containing the MBS, the FBSs and the receivers in the D2D communications), we get the accessing limited area (ALA) based on the SINR requirements γ of all the SRs and then distribute the upcoming MUs to the alternative adjacent FBSs fairly through D2D-based relay communications considering the following aspects: the distances between the upcoming MUs and the alternative FBSs, the fair usage of the resource of the FBSs and the remaining energy at the upcoming MUs.

The organization of the paper is as follows. In Section II, the system model is described. The load balancing for D2D-based relay communications in heterogeneous network and the interference management under the γ-ALA control scheme is proposed in Section III. The performances of the proposed method are demonstrated via MATLAB simulations in Section IV. Finally, conclusions are presented in Section V.

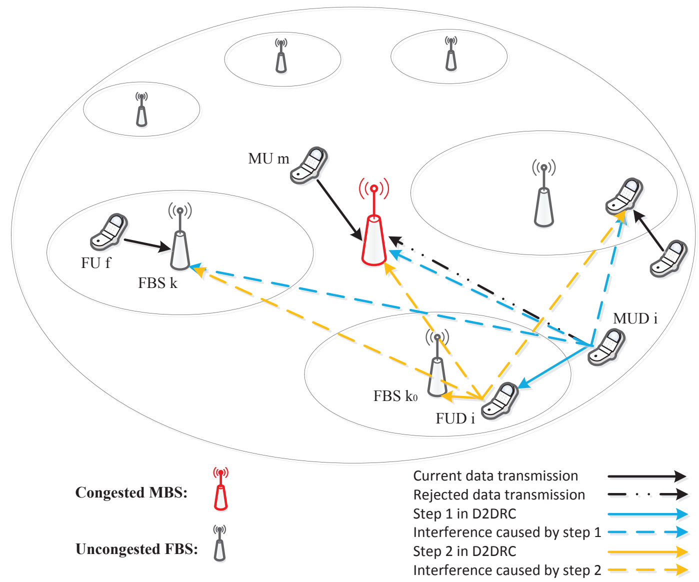

Fig. 1. System model of a three-tier HetNet.

II. System Model

A. Network model

As illustrated in Fig. 1, we consider an OFDMA-based three-tier HetNet with a single MBS, K FBSs and D D2D pairs. Since the MBS and the FBSs are assumed to be connected through high speed low-latency backhaul, tight coordination among the BSs is possible. The FBSs reuse part of the resource of the MBS and may cause interference to each other when some adjacent FBSs reuse the same resource simultaneously. The D2D communications are constituted as a method of offloading the traffic from the congested MBS to the nearby uncongested FBSs and reuse the uplink resource of the corresponding FBSs [11]. The MUs work under the D2D communication mode (MUD) and the FUs work under the D2D communication mode (FUD) belong to different tiers. Therefore, both cross-tier interference between the MUs and the FUs, the MUs and the D2D pairs, the FUs and the D2D pairs and co-tier interference among the FUs and among the D2D pairs may be the bottlenecks of the network performance.

B. Channel model

We consider a distance-dependent path-loss for modeling the propagation channel. In particular, the path-loss model is defined as

$$P_{i,j} = c \cdot (d_{i,j})^{-\alpha} \cdot P_i, \quad (1)$$

where P_i refers to the initial transmitting power at the transmitter i and $P_{i,j}$ refers to the power measured at receiver j $d_{i,j}$ away from transmitter i. c and α are path-loss constant and path-loss exponent, respectively [12][13].

III. Three-tier HetNet with resource partitioning

A. Aggregating the femtocells with graph coloring

As the femtocells reuse part of the resources of the MBS, the resources should be well partitioned to reduce the mutual interference among the femtocells. Different aggregations of the femtocells using the same resources may lead to different network performance and finding the optimal aggregation of femtocells is a complex problem [3][4]. In the conventional set up, the frequency resource partitioning of the femtocells is based on the maximum SINR at the receiver. We simplify this problem by taking the graph coloring algorithm in [14]. Specifically, any two FBSs with a distance $d_{pq} < d_{th}$ are identified as mutually interfering femtocells that cannot use the same frequency resource simultaneously. Parameter d_{th} is a pre-determined threshold that may depend on the femtocell deployments.

B. Load balancing with fair capacity usage of the femtocells

In the conventional setup, users usually simply choose the BS with the maximum received SINR to associate. This may not suitable to our framework as the FBSs are mostly resource limited and are deployed to serve the FUs rather than the MUs. To keep the new call blocking probability (NCBP) of the FUs below a pre-defined threshold, the resource limited FBS would not admit the accessing of the upcoming MUs when the number of its current connecting MUs is significantly higher than other alternative FBSs. These contribute to that the MUs connected to the FBSs through D2D communications should be distributed to the FBSs fairly to the greatest extent[15].

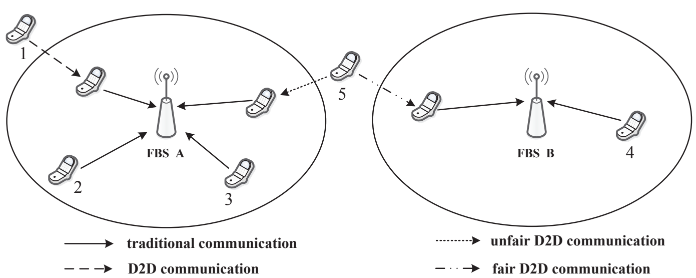

Fig. 2. Example of the capacity usage of the femtocells.

As shown in Fig. 2, there are 5 users and 2 FBSs with unbalanced associations. The FUs in the FBS A suffer a higher NCBP than those in the FBS B, and this situation would be even worse after an upcoming user, which is denoted as user 5, has associated to the FBS A. To resolve this unfairness problem, we propose an architecture for the congested macro-cell through allocating MUs to the FBSs fairly considering the following four aspects: 1) the normalized distance between the MU m and the alternative FBS k, denoted as $D_{m,k}$, 2) the load ratio at the alternative FBS k, denoted as R_r, 3) the ratio of the FUs associated to the alternative FBS k, denoted as R_k, 4) the remaining power budget of the battery-driven MU m, denoted as P_m. It is obviously that as long as the P_m of the upcoming user is higher than a threshold P_{th}, the MU should choose an FBS with a lower R_r when the alternative FBSs have the same R_k for the constrain of fair accessing, even if the chosen FBS is not with the maximum received SINR. However, to ensure complete transmission when the power budget of the MU runs below P_{th}, the MU directly chooses the nearest uncongested FBS. Hence, the particular FBS k_o is obtained as follows:

$$k_o = \begin{cases} \arg\min\limits_{k} \left(\omega_1 R_r + \omega_2 R_k + \omega_3 D_{m,k}\right), P_m \geq P_{th} \\ \arg\min\limits_{k} D_{m,k}, P_m < P_{th} \end{cases}, \tag{2}$$

$$R_r = l_k / N_0, \tag{3}$$

$$R_k = n_k / N_k, \tag{4}$$

$$D_{m,k} = \frac{\sqrt{\left(x_m - a_k\right)^2 + \left(y_m - b_k\right)^2}}{R_{FBS} + R_{D2D}}, \tag{5}$$

where ω_1, ω_2 and ω_3 are the weighting factors, l_k is the number of the occupied resources at the FBS k, n_k is the number of FUs associated to the FBS k, N_0 and N_k are the total number of the resources and the FUSs of the FBS k, R_{FBS} and R_{D2D} are the radius of femtocell and the maximum D2D communication distance criterion, respectively. (x_m, y_m) and (a_k, b_k) are the locations of the MU m and FBS k, respectively.

C. The selection of the relay node

As the MUs and FUs are usually battery-driven, choosing which FU to establish an energy efficient D2D communication with the MU is also a problem to be settled after getting the optimal FBS k_0 to associate. From (1), we can fined that the energy consumption is based on the distance between the transmitter and the receiver. So the optimal FU α used for relay is obtained as follows:

$$\alpha = \arg\min_{j} \left(d_{m,j} + d_{j,k_0}\right), \tag{6}$$

$$d_{m,j} = \sqrt{\left(x_m - x_j\right)^2 + \left(y_m - y_j\right)^2}, \tag{7}$$

$$d_{j,k_0} = \sqrt{\left(x_j - a_{k_o}\right)^2 + \left(y_j - b_{k_0}\right)^2}, \tag{8}$$

where (x_j, y_j) is the location of the idle FU j in the coverage of the FBS k_0. The $d_{m,j}$ and d_{j,k_0} are the distance from the MU m to the FU j and the distance from the FU j to FBS k_0, respectively. FBS k_0 then sends the information of the FU α to the MBS.

D. Strategy for interference management

We propose a γ-ALA control scheme in which one MU, F_r FUs and D_r D2D pairs use the same frequency r to transmit data simultaneously, as illustrated in Fig. 1. The γ-ALA is defined as the area centered on the SR, in which adding a new user will cause the received SINR lower than the predefined threshold γ at a certain frequency. The γ-ALA scheme we proposed is based on the following assumptions: (1) The SRs know the location information of the MUs, the FUs and the D2D pairs, (2) The MUs, the FUs and the D2D transmitters work at the same power P_0. Under these assumptions, the SRs can calculate the corresponding minimum radius of the γ-ALA at every frequency. When an upcoming MU asks for data transmitting, the FBS calculates the available frequencies the MU can use based on the location of the MU according to the γ-ALA scheme, and then selects the one, denoted by frequency r^*, that maximizes the data transmitting rate of the MU.

1) The γ-ALA control scheme: In fig. 1, we denote the locations of the MU m, the MBS, the FU f, the FBS k and the D2D pair i working on the frequency r as $L_m^r = (x_m, y_m)$, $L_{MBS}^r = (a, b)$, $L_f^r = (x_f, y_f)$, $L_k^r = (a_k, b_k)$ and $L_{Di}^r = (x_{Di}, y_{Di})$ respectively. We define the γ-ALA as the area centered on the SR, in which adding a new user will cause the received SINR lower than the predefined threshold γ at a certain frequency. The constrain of the received SINRs for γ-ALA are expressed as

$$\gamma_m^r = \frac{P_{m,M}}{\sum\limits_{f=1}^{F_r} P_{f,M} + \sum\limits_{i=1}^{D_r} P_{Di,M} + G} \geq \gamma_M, \tag{9}$$

$$\gamma_k^r = \frac{P_{f,k}}{P_{m,k} + \sum\limits_{j\neq f,j=1}^{F_r} P_{j,k} + \sum\limits_{i=1}^{D_r} P_{Di,k} + G} \geq \gamma_F, \tag{10}$$

$$\gamma_{Di}^r = \frac{P_{Di,Di}}{P_{m,Di} + \sum\limits_{f=1}^{F_r} P_{f,Di} + \sum\limits_{j\neq i,j=1}^{D_r} P_{Dj,Di} + G} \geq \gamma_D, \tag{11}$$

where γ_m^r, γ_k^r and γ_{Di}^r mean the SINRs received at the MBS, the FBS k and the D2D pair i on the frequency r respectively. G is the power spectrum density of AWGN. To maintain the link reliability of the whole system, it is assumed that the effective SINRs must be at least equivalent to the predefined SINR threshold γ_{MBS}, γ_{FBS}, γ_{D2D} respectively, even if the interference of the upcoming user was involved. Therefore, we rewrite the above equations as

$$\frac{P_{m,M}}{\sum\limits_{f=1}^{F_r} P_{f,M} + \sum\limits_{i=1}^{D_r} P_{Di,M} + G + P_{N,M}} = \gamma_M, \tag{12}$$

$$\frac{P_{f,k}}{P_{m,k} + \sum\limits_{j\neq f,j=1}^{F_r} P_{j,k} + \sum\limits_{i=1}^{D_r} P_{Di,k} + G + P_{N,k}} = \gamma_F, \tag{13}$$

$$\frac{P_{Di,Di}}{P_{m,Di} + \sum\limits_{f=1}^{F_r} P_{f,Di} + \sum\limits_{j\neq i,j=1}^{D_r} P_{Dj,Di} + G + P_{N,Di}} = \gamma_D, \tag{14}$$

where the $P_{N,M}$, $P_{N,k}$ and $P_{N,Di}$ mean the power measured at the MBS, the FBS k and the D2D pair i from the upcoming D2D pair with the position (x_N, y_N), respectively. By substituting (1) and (9)-(11) into (12)-(14), the constrains can be rewritten as

$$d_{N,M}{}^2 \geq d_{m,M}{}^2 \left(\frac{1}{\gamma_M} - \frac{1}{\gamma_m^r} \right)^{2\alpha}, \tag{15}$$

$$d_{N,k}{}^2 \geq d_{f,k}{}^2 \left(\frac{1}{\gamma_F} - \frac{1}{\gamma_k^r} \right)^{2\alpha}, \tag{16}$$

$$d_{N,Di}{}^2 \geq d_{Di,Di}{}^2 \left(\frac{1}{\gamma_D} - \frac{1}{\gamma_{Di}^r} \right)^{2\alpha}, \tag{17}$$

both the MUD and FUD in the D2D pair must satisfy the position constrain.

With the interactions of the SRs, the channel quality information (CQI) containing the SINRs and the positions of the transmitters and the receivers are exactly known. So the right part of the (15), (16) and (17), which we denote as $R_m^r{}^2$, $R_k^r{}^2$ and $R_{Di}^r{}^2$ respectively, can be calculated previously to the upcoming D2D communication. Since then, each FBS can calculate the minimum radius of the γ-ALA at every frequency they can use and collects the same information from the FUDs within its coverage. After doing these, the FBSs send the results to the MBS. The MBS combines the results with the position of the upcoming D2D pair and gets all the available frequencies can be used at FBS k_0. The MBS then sends the corresponding information to the FBS k_0.

2) Reliable transmission criterion: To have the reliable transmission for D2D-based relay communications, the effective received SINRs at the FUD α and the FBS k_0 should be higher than the pre-defined effective SINR threshold γ_{D2D} and γ_{FBS} respectively and they can be expressed as

$$\gamma_{D\alpha}^r = \frac{P_{D\alpha,D\alpha}}{P_{m,D\alpha} + \sum\limits_{f=1}^{F_r} P_{f,D\alpha} + \sum\limits_{j=1}^{D_r} P_{Dj,D\alpha} + G} \geq \gamma_D, \tag{18}$$

$$\gamma_{k_0}^r = \frac{P_{D\alpha,k_0}}{P_{m,k_0} + \sum\limits_{f=1}^{F_r} P_{f,k_0} + \sum\limits_{j=1}^{D_r} P_{Dj,k_0} + G} \geq \gamma_F. \tag{19}$$

The denominators of the above (18) and (19) are the signal power received at the FUD α and the FBS k_0, which are known to the FUD α and the FBS k_0 ahead of the D2D communication start. The numerators of the above (18) and (19) can be get through (1). The FUD α then gets all the available frequencies and sends the results to the FBS k_0.

3) The available data rate: With the information of the minimum radius of the γ-ALA criterion and the reliable transmission criterion, the FBS k_0 can effectively select the suitable frequencies for the D2D-based relay communications to eliminate the harmful interference to the SRs, while having the reliable transmission quality. We denote the set of the available frequencies as Ω_{k_o}. The FUD α and the FBS k_0 calculate the achievable data rate at every frequency r in set Ω_{k_o} respectively as follows:

$$r_{D\alpha}^{r} = B\log_2\left(1+\gamma_{D\alpha}^{r}\right), \tag{20}$$

$$r_{k_0}^{r} = B\log_2\left(1+\gamma_{k_o}^{r}\right), \tag{21}$$

where B is the bandwidth corresponding to frequency r.

Since we are considering a two hop communication approach, the end-to-end data rate for the D2D-based relay communication is the half of the minimum achievable data rate over two hops, i.e.,

$$R^r = \frac{1}{2}\min\left(r_{D\alpha}^{r}, r_{k_0}^{r}\right). \tag{22}$$

4) Spectrum Resource Allocation: The resource management for the D2D-based relay communications can be achieved by the frequency selection. The procedures of the frequency selection is described in the following:

(1) The FBS k_0 gets the available frequency set Ω_{k_o}.

(2) The FBS k_0 calculates the available data rate R^r at every frequency r in the set Ω_{k_o}.

(3) The FBS k_0 selects the frequency r^* that maximize the data rate R^r and distributes it to the MBS and the FUD. The MBS relay the information to the MUD.

(4) The MUD and the FUD form the D2D pair and start the data transmission.

IV. Performance evaluation

In this section, we show the performance improvements of the spectrum resource management for the OFDMA-based heterogeneous Macrocell/Femtocell/D2D network systems subjected to the complicated three-tier interference. Our simulation environment is shown in Fig. 1. We consider a circle area with a radius of 250(m), where the MBS is located at the center of the area. 10 disjiont FBSs, with a radius of 40(m), are uniformly distributed in the macrocell coverage area with a minimum distance of 180(m) from the MBS. 40 FUs are uniformly distributed within the coverage of one FBS. 600 MUs are uniformly distributed in the coverage of the macrocell while outside those of the femtocells. The transmission power of the MUs, the FUs, the MUDs and the FUDs are 23(dBm). The total number of RBs for the users available at the MBS is 200, which is divided into 5 parts for the reuse of the FBSs. Each of the FBSs can reuse $N_0 = 40$ serial resource blocks (RBs). The threshold d_{th} used for graph coloring is set 200(m). The MBS is assumed to be congested, i.e., all the RBs are occupied by the MUs. The predefined effective SINR threshold of the MBS, the FBSs and the FUDs are -2.5(dB). The weighting factors ω_1, ω_2 and ω_3 are all set 1/3.

We consider four scenarios. Scenario I represents the traditional cellular mode. Scenario II represents the traditional HetNet mode without D2D. Scenario III represents the situation that the D2D pair directly chooses the alternative FBS with the maximum received SINR to associate under the γ-ALA control scheme. Scenario IV represents the situation that the D2D pair chooses the alternative FBS with fair capacity usage of the femtocells under the γ-ALA control scheme.

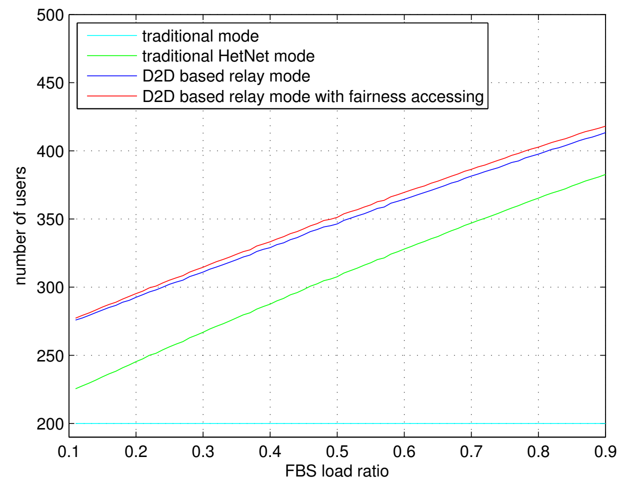

Fig. 3. Users performance against the load ratio of the FBS.

A. Impact of the resource management on number of the total users

Fig. 3 shows the number of the total users performance of the traditional cellular mode, the traditional HetNet mode, the D2D based relay communications and the D2D based relay communications with fairness accessing against the load ratio R_r of the femtocells in the shared spectrum allocation scheme. The distance from the MUD to the FUD is within a distance criterion of 20(m). From the figure, we have the following observations:

1) The proposed resource allocation can effectively distribute the RBs for the D2D-based relay communications to accommodate more users while guaranteeing the accessing of the pre-existing users (Scenarios II). The performance of our method can get even better if taking the fairness usage of the FBSs into consideration (Scenarios III).

2) As the resource usage ratio R_r of the femtocells increases, the gap between the performance of Scenarios II and the Scenarios III grows since the MUDs are distributed nearly equally to the alternative FBSs considering the load at the corresponding FBSs in the Scenarios III . The imbalance of the usage of the FBSs has been alleviated.

3) From Scenarios II and Scenarios III, the number of the D2D communications under the proposed method degrade linearly with the growing of the resource usage ratio R_r of the femtocells. This means that the availability of the FUD and the corresponding uncongested FBS rather than

the interference criterion, both the cross-tier and the co-tier interference criterion, are the determinants in the formation of the D2D-based relay communications.

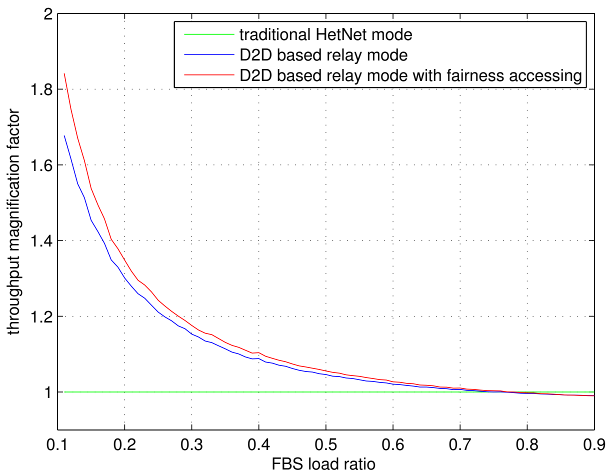

Fig. 4. Throughput performance against the load ratio.

B. Impact of the resource management on throughput

Fig. 4 shows the total throughput magnification factor of the traditional HetNet mode, the D2D based relay communications and the D2D based relay communications with fairness accessing compared to the traditional HetNet mode against the resource usage ratio R_r of the femtocells in the shared spectrum allocation scheme. The distance from the MUD to the FUD is within a distance criterion of 20(m). From the figure, we have the following observations:

1) Although the disparity of the throughput between Scenarios II (Scenarios III) and the traditional HetNet degrades as the resource usage ratio R_r increases, the magnification factor of the throughput of Scenarios II (Scenarios III) to that of traditional HetNet still keeps larger than 1 even the R_r reaches 0.8. This implies that the throughput brought by the D2D based relay communications can help improving the throughput of the whole system.

2) The outperformance brought by the D2D based relay communications considering the fairness usage of the FBSs (Scenarios III) is more than that based on the maximum received SINR from the FBSs (Scenarios II). As the load ratio R_r increases, the cross-tier and the co-tier interference rise, the available RBs and the idle FUs at the alternative FBS decreases at the same time. The gap between Scenarios II and Scenarios III decrease for the users in Scenarios III suffer more interference caused by a larger amount of users working on the same RB simultaneously.

3) Compared to Scenarios I, Scenarios III can improve 10% higher total throughput when the the load ratio of the femtocells is 0.4.

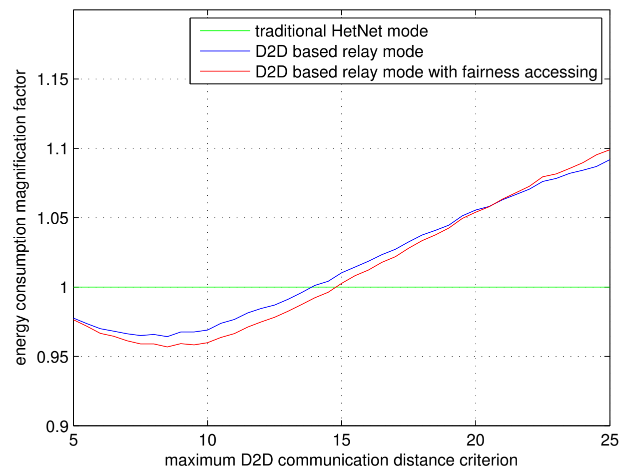

Fig. 5. Energy consumption magnification factor per bit

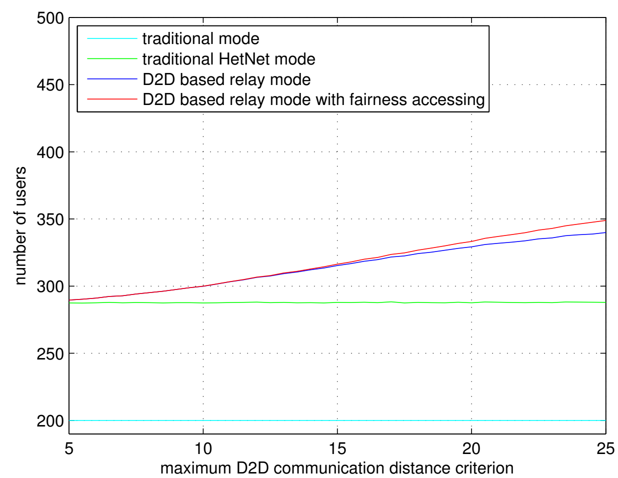

Fig. 6. Users performance against the D2D distance.

C. Impact of the maximum D2D communication distance criterion on energy consumption per bit

Fig. 5 and Fig.6 show the energy consumption magnification factor per bit and the number of users of the traditional HetNet mode, the D2D based relay communications and the D2D based relay communications with fairness accessing against the maximum D2D communication distance criterion in the shared spectrum allocation scheme. From the figures, we have the following observations:

1) The low power consumption characteristic of the short range D2D communication contributes to the better energy efficiency. As the maximum D2D communication distance criterion increases, the probability of potential D2D communications goes up, leading to more users and more interference in Scenarios II and Scenarios III. Thus the performance of the energy consumption per bit of Scenarios II and Scenarios III increase for more users when the maximum D2D commu-

nication distance criterion is low and drop for more intense interference when the maximum D2D communication distance criterion goes higher.

2) The introduction of D2D based relay communication within a maximum D2D communication distance of 15(m) can promote the system performance with more users and less energy consumption.

V. Conclusions

In this paper, we proposed a strategy for load balancing in an OFDMA-based three-tier HetNet and presented a comprehensive resource allocation framework for D2D-based relay communications. The femtocells that can share the same resources were aggregated by graph coloring and the γ-ALA control scheme was proposed to mitigate the cross-tier and co-tier interference. We have utilized the received SINR and the SINR criterion of the current users to calculate the set of RBs suitable for the MU denied by the congested MBS and chosen the RB with the maximum transmission rate to form a D2D-based relay communication to offload the traffic to the adjacent uncongested FBS. The performance of the proposed strategy has been evaluated through simulation and we have observed that the proposed strategy is essential to the success of improving the total number of users, the system throughput and the energy efficiency. Our proposed strategy also reveals the possibility of improving the network performance by deploying FBSs and D2D communications. However, to develop a complete D2D-based relay communication, this work can be extended considering the D2D communication set up process and the system payback for the workload of the FUs acted as relay node. Encouraging the FUs to participate in such D2D based relay communications is worth investigating.

References

[1] Cisco Visual Networking Index: Forecast and Methodology, 2009-2014. [Online]. Available: www.cisco.com.

[2] A. Damnjanovic, J. Montojo, Y. Wei, et al. “A survey on 3GPP heterogeneous networks,” IEEE Wireless Communications, vol. 18, no. 3, pp. 10-21, 2011.

[3] F. Khozeimeh, S. Haykin. “Self-organization dynamic spectrum management for cognitive radio networks,” Communication Networks and Services Research Conference (CNSR), pp. 1-7, 2010.

[4] P. Setoodeh, S. Haykin. “Robust transmit power control for cognitive radio,” Proceedings of the IEEE, vol. 97, no. 5, pp. 915-939, 2009.

[5] M. Tehrani, M. Uysal, H. Yanikomeroglu. “Device-to-device communication in 5G cellular networks: challenges, solutions, and future directions,” IEEE Communications Magazine, vol. 52, no. 5, pp. 86-92, 2014.

[6] A. Laya, K. Wang, A. Widaa, et al. “Device-to-device communications and small cells: enabling spectrum reuse for dense networks,” IEEE Wireless Communications, vol. 21, no. 4, pp. 98-105, 2014.

[7] X. Lin, J. Andrews, A. Ghosh, et al. “An overview on 3GPP device-to-device proximity services,” IEEE Communications Magazine, vol. 52, no. 4, pp. 40-48, 2014.

[8] Y. Cao, T. Jiang, C. Wang, et al. “CRAC: cognitive radio assisted cooperation for downlink transmissions in OFDMA-based cellular networks,” IEEE Journal on Selected Areas in Communications, vol. 30, no. 9, pp. 1614-1622, October 2012.

[9] Y. Cao, X. Chen, T. Jiang, and J. Zhang, SoCast: social ties based cooperative video multicast, in IEEE International Conference on Computer Communications (INFOCOM), Toronto, ON, Canada, April 2014.

[10] A. Asadi, Q. Wang, V. Mancuso. “A survey on device-to-device communication in cellular networks,” IEEE Communications Surveys & Tutorials, vol.16, no.4, pp.1801,1819, Fourth quarter 2014.

[11] L. Lei, Z. Zhong, C. Lin, et al. “Operator controlled device-to-device communications in LTE-advanced networks,” IEEE Wireless Communications, vol. 19, no. 3, pp. 96-104, 2012.

[12] T. Rappaport. Wireless Communications: Principles and Practice, 2nd edition. Prentice Hall, 2001.

[13] H. Min, J. Lee, Su. Park, et al. “Capacity enhancement using an interference limited area for device-to-device uplink underlaying cellular networks,” IEEE Transactions on Wireless Communications, vol. 10, no. 12, pp. 3995-4000, 2001.

[14] D. Br’elaz. “New methods to color the vertices of a graph,” Communications of the ACM, vol. 22, no. 4, pp. 251-256, 1979.

[15] K. Lee, S. Kim, S. Lee, et al. “Load balancing with transmission power control in femtocell networks,” 2011 13th International Conference on Advanced Communication Technology (ICACT), pp. 519-522, 2011.

[16] M. Hasan, E. Hossain, D. Kim. “Resource allocation under channel uncertainties for relay-aided device-to-device communication underlaying LTE-A cellular networks,” IEEE Transactions on Wireless Communication, vol. 13, no. 4, pp. 2322-2338, 2014.

[17] R. Yin, G. Yu, C. Zhong, et al. “Distributed resource allocation for D2D communication underlaying cellular networks,” IEEE International Conference on Communications Workshops (ICC), pp. 138-143, 2013.

[18] D. Lee, K. Choi, W. Jeon. “Two-stage semi-distributed resource management for device-to-device communication in cellular networks,” IEEE Transactions on Wireless Communication, vol. 13, no. 4, pp. 1908-1920, 2014.

[19] A. Tsai, L. Wang, J. Huang. “Intelligent resource management for device-to-device (D2D) communications in heterogeneous networks,” Wireless Personal Multimedia Communications(WPMC), pp. 75-79, 2012.