Improving the Spectral Efficiency in Dense Heterogeneous Networks Using D2D-Assisted eICIC

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***Abstract*—Heterogeneous Networks (HetNets) that consist of macro base stations (MBSs) and small base stations (SBSs) are a key architectural drive for achieving the high spectral efficiency (SE) in 5G and beyond. Moreover, device-to-device (D2D) communications underlaying mobile networks can provide reliable communications and add SE gains. A major challenge in HetNets is the inter-cell interference (ICI) due to the coexistence of multiple tiers of base stations (BSs). To tackle this challenge, the enhanced inter-cell interference coordination (eICIC) scheme was adopted by 3GPP. In eICIC the MBSs mute their transmission during the so-called "almost blank subframes" (ABS). This muting strategy causes resources reduction to the MBS users (MUEs). We propose the use of D2D communication to forward the transmission from the SBS to the MUEs during ABS subframes, by using inactive UEs to relay the downlink transmission, when the destination UEs are outside the coverage of the BS. We use a heuristic resource allocation (RA) algorithm based on the traffic load at the SBSs that integrates eICIC with D2D communications to avoid the service degradation during the time-domain muting. Simulation results of a HetNet with D2D-eICIC show that the SE of our approach outperforms other interference management approaches.**

***Index Terms*— HetNets, D2D, SE, eICIC, ABS and RA.**

I. Introduction

Maximizing the spectrum efficiency is one of the major requirements in the design of 5G and future mobile networks. The heterogeneous deployment of macro base stations (MBSs), small base stations (SBSs) and device-to-device (D2D) communications is seen as one of the main technology drives that could boost the spectrum efficiency if frequency reuse over the different tiers of the wireless network is applied [1], [2].

However, user equipments (UEs) are normally associated with the base station that has the highest received signal strength which makes the SBSs underutilized due to their low transmission power. For this reason, 3GPP introduced a virtual expansion of the coverage area of the SBSs by adding a bias value to their received signal at the UEs [1]. This is known as the cell range expansion (CRE) and is shown in Fig. 1.

On one hand, CRE helps offloading UEs from the MBSs to the SBSs. But on the other hand, it creates a vulnerable region at the edge of the SBSs where UEs are prone to high interference from the MBS. One of the interesting approaches to protect those edge UEs (EUEs) is the enhanced time-domain inter-cell interference coordination scheme (eICIC) [1]. In eICIC, the MBSs mute their downlink transmission during certain subframes so the SBSs can serve the EUEs. Those subframes are known as almost blank subframes (ABS) and their value is related to the SBS's expanded region. However, the main drawback of eICIC is that the transmission rate of the MBS users (MUEs) is reduced during the ABS subframes.

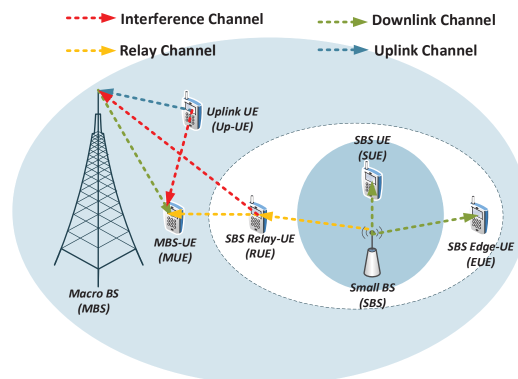

Fig. 1: Heterogeneous Radio Access Network System Model with Cell Range Expansion and Supporting D2D Communication

In this paper, we propose the performance improvement of MUEs during ABS subframes by integrating D2D communications with eICIC. We consider using inactive UEs as relays to the MUEs to avoid the service degradation due to eICIC. To the best of our knowledge, this is the first attempt to integrate D2D communications with eICIC in dense HetNets to mitigate the performance degradation of the MBS. We propose and evaluate a heuristic spectrum efficiency-aware resource allocation technique that exploits the incentive of inactive UEs to cooperate in serving as relays to deliver the downlink transmission to MUEs during ABS subframes.

The integration of D2D communications with cellular networks has been studied in the literature from different aspects. In [3], the authors proposed to use D2D communications as a relay system to support the BSs in their communication with the out-of-coverage UEs. Relays where used in [4] to support the uplink communication between the UEs and the BSs and the communication between each D2D pair. Few studies were concerned with the performance degradation of MUEs when eICIC is used. In [5] and [6] eICIC was combined with the coordinated multipoint beamforming (CoMP) scheme and an adaptive system was implemented in [5] to switch between eICIC and CoMP depending on the channel quality and the interference conditions. However, the complexity of CoMP is high and difficult to implement in dense network scenarios as it requires full knowledge of the channel state information and tight coordination between the BSs. In [7], the authors considered the deployment of a two-tier HetNet with the support of D2D communications where D2D was used to offload the downlink traffic from the BSs by exploiting caching at the UEs. The authors in [8] proposed to replace ABS subframes by D2D communication to serve the edge user which resulted in reduced sum rate of SBS as they did not consider the interference at the EUEs from the MBSs. Finally, D2D was used in [9] and [10] to improve the video delivery in HetNets using eICIC but without considering the MUEs performance. We adopt a different approach in this paper where we use relaying and D2D communications to support eICIC in combating the inter-cell interference.

II. System Model

We consider a multi-tier HetNet as shown in Fig. 1 which is similar to the current LTE-Advanced network [11]. We study the sum offered rate using a single MBS denoted by m and a set of SBSs $\mathcal{S} = \{1, ..., S\}$. Here, SBSs refer to any low power nodes operating on the same spectrum with the MBS, e.g. Pico BSs. Each of the MBS and the SBSs have a set of associated UEs for downlink transmission and denoted by MBS users equipment (MUEs) $\mathcal{K}^{mu} = \{1, ..., K^{MU}\}$ and SBS s users equipment (SUEs) $\mathcal{K}_s^{su} = \{1, ..., K_s^{SU}\}$, respectively. We also refer to the offloaded UEs due to CRE as the edge users equipment (EUEs) $\mathcal{K}_s^{eu} = \{1, ..., K_s^{EU}\}$ at each SBS s .

We assume that there is a set of relay UEs (RUEs) $\mathcal{K}_s^{ru} = \{1, ..., K_s^{RU}\}$ at each SBS s that can operate on D2D mode and serve as relays between the SBSs and the MUEs during ABS subframes. RUEs are associated with the border region of the SBSs to guarantee minimum distance with the MUEs. The task of the RUEs is to operate only as relays and no caching is assumed in the current work. We also assume that the RUEs operate in half duplex mode to avoid self-interference issues. We assume that D2D communication shares the uplink spectrum with cellular network [12]. We also assume that the processes of D2D discovery and partner selection are performed at an initial phase prior to resource allocation and D2D association is fixed during the complete downlink frame[1].

Fig. 2 shows the downlink frame structure according to LTE standards [14]. We consider a number of $\mathcal{T}$ subframes with $\mathcal{T}^{RS} = \{1, ..., T^{RS}\}$ regular subframes (RS) and $\mathcal{T}^{ABS} = \{1, ..., T^{ABS}\}$ ABS subframes, and $\mathcal{N}_t = \{1, ..., N_t\}$ resource blocks (RBs) at each subframe. BSs can allocate multiple RBs to the UEs depending on the required data rates. The fundamental idea of our approach is to exploit the frame structure to relay the downlink packets from the SBSs to the MUEs through the RUEs during ABS subframes as shown in Fig. 2. We assume that a central entity at the core network, which is connected to the BSs via optical fiber back-haul links, is responsible for allocating the resource blocks to the devices,

[1]Several studies are concerned with D2D discovery and partner selection (e.g. [13]) which is out of the scope of this study.

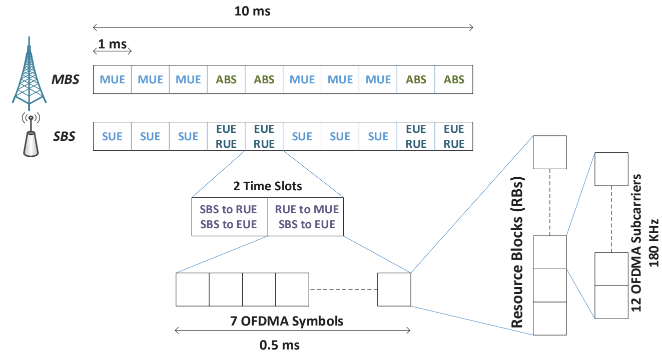

Fig. 2: Downlink Frame Structure

performed in subframe bases to guarantee full synchronization [11]. We assume that BSs have global knowledge of the channel information to facilitate the allocations of RBs.

Based on these assumptions, the content requested by all the users is delivered through both the MBS and the SBSs. Hence, MUEs are served through direct links with the MBS and through D2D links with the SBSs. As shown in Fig. 2, during ABS subframes, the MBS does not transmit to the MUE. It is also shown that ABS subframes are divided into two time slots. In the first slot, the SBSs transmit to the RUEs. While in the second slot, the RUEs forward the packets to the MUEs using decode and forward (DF) protocol. Note that during ABS subframes, the SBS is able to transmit to the EUEs as well since orthogonal OFDMA subcarriers in the frequency domain are used during the same time slot. However, this highly depends on the traffic load at the SBS and the only drawback that may occur is when the SBSs are fully loaded and need to trade-off between the EUEs and MUEs.

III. Spectral Efficiency Analysis:

In this section, we study the spectrum efficiency of the different nodes in the HetNet using the achievable sum-rate in both the RS and ABS subframes. We use the Shannon formulation to describe the maximum theoretical achievable rate [15]. As shown in Fig. 2, the communication between the SBSs and the MUEs during the ABS subframe is performed over two hops (i.e., SBS to RUE and RUE to MUE) using the DF protocol at the relay UEs [16]. This means that the end-to-end multi-hop rate needs to be considered.

A. Direct Channel Rate:

At each RS subframe, the signal to interference and noise ratio (SINR) at MUE k^{mu} from MBS m is given by

$$\gamma_{m,mu}^{RS^{1,2}} = \frac{p_m g_{m,mu}}{\sum_{s=1}^{S} p_s g_{s,mu} + \sigma_{mu}}. \quad (1)$$

Similarly, the downlink SINR at SUE k_s^{su} from SBS s during the regular subframes is given by

$$\gamma_{s,su}^{RS^{1,2}} = \frac{p_s g_{s,su}}{p_m g_{m,su} + \sum_{s'=1, s \neq s'}^{S} p_{s'} g_{s',su} + \sigma_{su}}, \quad (2)$$

where p_m and p_s are the transmission power of MBS m and SBS s, respectively. $g_{m,mu}$ and $g_{s,su}$ are the channel gains from the MBS m to the MUE mu and from the SBS

s to the SUE k_s^{su}, respectively. All the channel coefficients are independent and identically distributed complex Gaussian random variables. The summation terms in the denominators of (1) and (2) represent the interference from the MBS and SBSs. σ_k is the additive white Gaussian noise power at receiver k. The superscripts ^{1,2} represent the first and second time slots of each subframe.

The achievable rates of MUE k^{mu} and SUE k_s^{su} at the first and second time slots of the RS subframes are given by

$$R_{m,mu}^{RS^{1,2}} = W_{RB} log_2 \left(1 + \gamma_{m,mu}^{RS^{1,2}}\right), \tag{3}$$

$$R_{s,su}^{RS^{1,2}} = W_{RB} log_2 \left(1 + \gamma_{s,su}^{RS^{1,2}}\right), \tag{4}$$

respectively, where W_{RB} is the bandwidth of the RB.

During the ABS subframes, the SBSs have direct communication links with the EUEs [2]. Hence, the received $SINR$ at the EUE k_s^{eu} from the SBS s during the first and second time slots of the ABS subframe is given by

$$\gamma_{s,eu}^{ABS^{1,2}} = \frac{p_s g_{s,eu}}{\sum_{s'=1, s \neq s'}^{S} p_{s'} g_{s',eu} + \sigma_{eu}}, \tag{5}$$

where p_s and $g_{s,eu}$ are the transmission power and the channel gain from SBS s to the EUE k^{eu}, respectively. The summation term in the denominator of (5) is the interference from SBSs other than s. Note that there is no interference from the MBS in (5) since it is not transmitting during ABS subframes. The achievable rate of EUE k_s^{eu} at the first and second time slots of the ABS subframe is given by

$$R_{s,eu}^{ABS^{1,2}} = W_{RB} log_2 \left(1 + \gamma_{s,eu}^{ABS^{1,2}}\right). \tag{6}$$

B. Relay Channel Rates:

The rate of the relay channel is computed over two hops during the ABS subframe. The first hop carries the transmission from the SBS to the RUE at the first time slot. The second hop carries the transmission from the RUE to the MUE at the second time slot. The SINR and the rate of RUE k_s^{ru} from SBS s at the first time slot of the ABS subframe are given by

$$\gamma_{s,ru}^{ABS^1} = \frac{p_s g_{s,ru}}{\sum_{s'=1, s \neq s'}^{S} p_{s'} g_{s',ru} + \sigma_{ru}}, \tag{7}$$

$$R_{s,ru}^{ABS^1} = W_{RB} log_2 \left(1 + \gamma_{s,ru}^{ABS^1}\right), \tag{8}$$

respectively. At the second time-slot of the ABS subframe, the RUE forwards the received content from the SBS to the MUE. We assume that RUEs use their full transmission power to forward the data and they do not have any other concurrent transmissions. Since D2D communication shares the uplink spectrum with the cellular network and the SBSs are responsible for allocating RBs to the D2D links, the only source of interference is the uplink transmission of other cellular UEs. We will explain in section IV the procedure to manage the cellular to D2D interference. Note that we consider only one D2D user and one cellular user are sharing the RBs.

[2]SBSs allocate orthogonal resources to both EUEs and RUEs.

The SINR and the achievable rate of MUE k^{mu} from RUE k_s^{ru} at the second time slot of the ABS subframe are given by

$$\gamma_{ru,mu}^{ABS^2} = \frac{p_{ru} g_{ru,mu}}{p_{up} g_{up,mu} + \sigma_{mu}}, \tag{9}$$

$$R_{ru,mu}^{ABS^2} = W_{RB} log_2 \left(1 + \gamma_{ru,mu}^{ABS^2}\right), \tag{10}$$

respectively, where p_{ru} and $g_{ru,mu}$ are the transmission power and the channel gain between RUE k_s^{ru} and MUE k^{mu}, respectively. The denominator of (9) represents the uplink cellular interference. p_{up} and $g_{up,mu}$ are the transmission power and the channel gain between the uplink cellular user $k^{up} \in \mathcal{K} = \{1, ..., k^{UP}\}$ and the MUE k^{mu}, respectively.
Finally, the end-to-end (E2E) achievable rate between the SBS s and MUE k^{mu} through RUE k_s^{ru} using DF protocol is given by the minimum achievable data rate of the two hops [16] as

$$R_{s,mu}^{e2e} = \frac{1}{2} \min \left\{ R_{s,ru}^{ABS^1}, R_{ru,mu}^{ABS^2} \right\} \tag{11}$$

As we can see from (11) that the E2E data rate is limited by the worst-channel achievable rate which is considered as the bottleneck for the relay channel capacity. We will show in section VII two different cases of the relay channel rate that affect the performance of our proposed D2D approach.

IV. D2D-Cellular Interference

We are considering the reuse of RBs between one D2D pair and one cellular user in the uplink spectrum. We define the set of D2D pairs as $\mathcal{D} = \{1, ..., D\}$ and the set of uplink users as $\mathcal{C}^{up} = \{1, , , C^{UP}\}$. We consider the selection of reuse partners that cause the least mutual interference. We evaluate the mutual interference by using the SINR of the uplink user given by γ_{up} and the D2D pair given by γ_d. The uplink SINR of cellular user C^{up} is given by

$$\gamma_{up} = \frac{p_{up} g_{up}}{p_d g_{d,up} + \sigma_{up}}, \tag{12}$$

where p_{up} and g_{up} are the uplink transmission power and channel gain of uplink user $c^{up} \in \mathcal{C}^{up}$. p_d and $g_{d,up}$ are the transmission power of the D2D pair $d \in \mathcal{D}$ and the channel gain between the D2D pair and the uplink user. The SINR of the D2D user is similar to (9). We formulate the resource reuse partner selection problem as

$$\underset{x_{up,d}}{\text{maximize}} \quad \sum_{c^{up}=1}^{C^{UP}} \sum_{d=1}^{D} \left(\gamma_{up} + x_{up,d} \gamma_d \right), \tag{13a}$$

$$\text{subject to} \quad \gamma_{up} \geq \xi^c, \qquad \forall c^{up} \in \mathcal{C}^{up}, \tag{13b}$$

$$\gamma_d \geq \xi^d, \qquad \forall d \in \mathcal{D}, \tag{13c}$$

$$\sum_{c^{up}=1}^{C^{UP}} x_{up,d} = 1, \quad \forall d \in \mathcal{D}, \tag{13d}$$

$$\sum_{d=1}^{D} x_{up,d} = 1, \quad \forall c^{up} \in \mathcal{C}^{up}, \tag{13e}$$

$$x_{up,d} \in \{0, 1\}, \forall c^{up} \in \mathcal{C}^{up}, \forall d \in \mathcal{D}, \tag{13f}$$

Algorithm 1 Procedure of Resource Reuse Partner Selection

Input: Estimation of the channel information between D2D pairs and uplink cellular users: $g_{d,up}$.
Output: Assignment of resource reuse partners $x_{up,d}$.
1: Check connections that satisfy the constraints (13b), (13c).
2: Find the weight of each connection using the objective function in (13a).
3: Use the Hungarian algorithm to find the matching between one uplink cellular user and one D2D pair that maximize the sum-rate.

where the binary indicator $x_{up,d} = 1$ if D2D pair d can share RBs with uplink cellular user c^{up}, and $x_{up,d} = 0$ otherwise. ξ^c and ξ^d are minimum SINR requirements of the cellular and the D2D communication, respectively. The problem in (13) is a combinatorial problem that has high computational complexity. Similar to [17] and [18], we adopt an efficient approach for solving this problem by using the well known Hungarian algorithm [19] for the selection of the reuse partners that maximize the spectral efficiency. We explain in Algorithm 1 the procedure of selecting the reuse partners. As an initial step, we reduce the complexity of implementation of the algorithm by reducing the size of the search space by omitting connections that do not satisfy the rate constraints in (13b) and (13c). We then find the weights of each possible connection using the SINR of each connection with respect to the mutual interference. The final step in the algorithm is to apply the Hungarian algorithm [3] to find optimum matching between the uplink cellular users and the D2D pairs.

V. Small Base Station Resource Allocation

The main challenge in implementing the proposed scheme is to avoid degrading the performance of the SBS edge users. Each SBS forwards the transmission to the MUEs while serving EUEs during the ABS subframes. The optimization problem of each SBS s sum-rate at ABS subframe is given by

$$\underset{x^{eu}_{t,n}}{\text{maximize}} \quad \sum_{t=1}^{T^{ABS}} \sum_{n=1}^{N_t} \left(\sum_{eu=1}^{K^{eu}} x^{eu}_{t,n} R^t_{eu} + \sum_{mu=1}^{K^{mu}} (1 - x^{eu}_{t,n}) R^{e2e,t}_{mu} \right) \tag{14a}$$

$$\text{subject to} \quad R^{abs}_{s,eu} \geq \xi^{eu}, \forall k^{ru}_s \in K^{RU}_s, \forall t \in T^{ABS} \tag{14b}$$

$$x^{abs}_s \in \{0,1\}, \forall t^{abs} \in T^{ABS}. \tag{14c}$$

where we drop the SBS s subscript for brevity. The binary indicator $x^{eu}_{t,n} = 1$ if the EUE k^{eu} is allocated RB n at subframe t and $x^{eu}_{t,n} = 0$ if MUE k^{mu} is allocated the RB. ξ^{eu} is the minimum QoS requirement of EUEs. Constraint (14b) is used to ensure that the quality of service of EUEs is above the minimum threshold. The optimization problem in (14) is an integer programming problem that requires high computational effort to find the optimal resource allocation. The reason is that each SBS needs to search over all associated EUEs and MUEs. Instead, we propose a heuristic resource allocation algorithm in section VI with low computational complexity and based on the traffic load at the SBS. Note that the optimization problem in (14) is based on a fixed ABS pattern and relay channel [4].

VI. Heuristic Resource Allocation Algorithm

The proposed heuristic algorithm is called D2D-eICIC and is summarized in Algorithm 2. We denote the traffic load at SBS s during ABS subframe t^{abs} as ψ^{abs}_s which counts the number of RBs N^{abs}_s demanded by the EUEs to meet their QoS requirements. The status of the traffic demand at each SBS is the main parameter that affects the performance of the proposed D2D-eICIC scheme. In the current work, we consider higher priority for the EUEs during ABS subframes. Hence, each SBS allocates its RBs to the EUE to satisfy their QoS demand before allocating the remaining RBs to the MUEs. It will be shown in section VII that the gains of the proposed algorithm depend highly on the traffic load. However, considering that cellular operators design their mobile network with a capacity that avoids congestion at the base stations in normal operating conditions, this means there are always RBs available to serve the MUEs in our case. In line (12) of the algorithm we initialize the counter for the traffic load which has to be less than the available resource blocks at each SBS to guarantee the gains of our approach.

Algorithm 2 Heuristic D2D-eICIC Algorithm

```
1:  Initialization: Estimate the global channel information.
    Associate RUEs K_s^ru with MUEs K^mu.
    Find resource reuse partners using Algorithm 1.
    Obtain ABS pattern form the core network.
2:  for t ∈ {1, ..., T}
3:      for n ∈ {1, ..., N_m^RS}
4:          Calculate R_{m,mu} using (3).
5:      end for
6:      for s ∈ {1, ..., S}
7:          for n ∈ {1, ..., N_s^RS}
8:              for k^su ∈ {1, ..., K^SU}
9:                  Calculate R_{s,su} using (4).
10:             end for
11:         end for
12:         Initialize traffic load counter: ψ_s^abs = 0.
13:         while ψ_s^abs < N_s^abs
14:             for n ∈ {1, ..., N_s^abs}
15:                 for k^eu ∈ {1, ..., K^EU}
16:                     Calculate R_{s,eu} using (6).
17:                     ψ_s^abs = ψ_s^abs + 1.
18:                 end for
19:                 for k^mu ∈ {1, ..., K^MU}
20:                     Calculate R_{s,mu}^e2e using (8), (10), (11).
21:                     ψ_s^abs = ψ_s^abs + 1.
22:                 end for
23:             end for
24:         end while
25:     end for
26: end for
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[3] We do not present the Hungarian algorithms here for space limitations but the reader can refer to [19] for more details on the well-known algorithm.

[4] We will consider the joint optimization of the resource allocation and the relay channel selection in our future work.

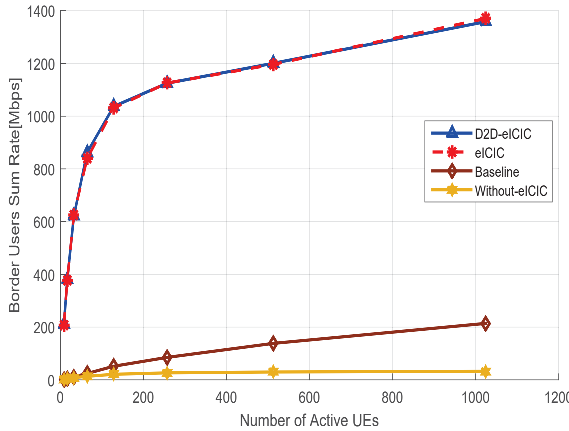

Fig. 3: Comparison between eICIC and Baseline Schemes Using EUEs Rate

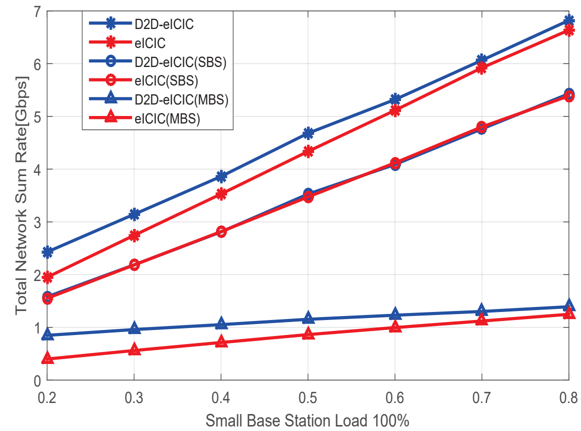

Fig. 4: Sum-Rate vs Traffic Load at SBSs

VII. Performance Evaluation

The parameters used in our Matlab simulation are chosen according to 3GPP standards and are shown in Table I. We assume a dense environment of UEs which simulates an urban area. The density of UEs is a parameter that we change during the simulation for performance evaluation. The network layout is shown in Fig. 5 and it adopts a coverage area of one MBS and several SBSs. Each of the MBS and SBSs are using an omni-directional antenna and represents one cell of coverage. Hence, the number of BSs and cells is equal. The SBSs are assumed to be Pico BSs that provide outdoor coverage and are distributed randomly in the service area using a Poisson distribution with density of 30 SBSs. The channel between the BS and the UE is modeled using the standard channel model by 3GPP [11] that accounts for multipath, shadowing and pathloss. The CRE bias value of the SBSs received power is 15 dB. The ABS subframes are chosen according to the most common values used in the literature which are $15/40$ subframes. During D2D communications, UEs are using their maximum transmission power and the choice of the D2D partner is based on the channel conditions between devices. The channel between each D2D pair is modeled using the standard channel model defined by 3GPP [11].

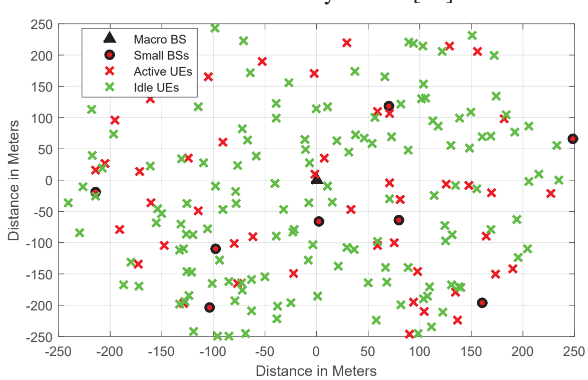

Fig. 5: Layout of the Simulated Heterogeneous Network

In Fig. 3 we compare our proposed D2D-eICIC approach with other three different approaches and for 50% traffic load at the SBSs. We consider the approach in [8] as a baseline technique where D2D communication is used to serve the EUEs during the whole downlink period instead of using ABS subframes. In Fig. 3 we present only the sum-rate of the edge users to show the gains achieved using the proposed D2D-eICIC in comparison with the baseline scheme. Besides, we can observe the poor performance of the edge users when neither D2D or eICIC are applied. Although the main advantage of using our proposed technique is to improve the performance of the macro base station users, we show in Fig. 3 that the performance of the edge users is not deteriorated with our scheme and it is similar to using eICIC without D2D.

In Fig. 4 we show the performance of D2D-eICIC in comparison to the traditional eICIC at different percentage of the traffic load at the SBSs and for a fixed number of 500 UEs. We can observe from the graph that the sum-rate of the MBS has increased when we used D2D communications during the ABS sub-frames. As we have explained in section VI that the SBS is giving more priority to the edge users in the allocation of RBs, we can see in the graph that the gain of the MBS sum-rate is decreasing when the traffic load at the SBSs is increasing, while the SBSs maintain the same sum-rate compared to the traditional eICIC. However, the total sum-rate of the network is always larger when D2D is integrated with eICIC. In Fig. 6 we show the sum-rate at 50% of traffic load at the SBS. We can see that by increasing the number of UEs in the network we can achieve more gains from D2D-eICIC. This explains the foreseen benefits of D2D communications in general which exploits the good channel conditions between

TABLE I: Simulation Parameters

Parameter	Value
Simulation	10000 Iterations per (4 x 10 ms Frame)
Wireless Environment	Dense Outdoor Urban
Cellular Layout	Hexagonal Grid with 2 km radius
Bandwidth, PRBs	10 MHz, 50/180 kHz
Tx Power and Gain for MBS, PBS and D2D	[46, 30 and 23] dBm, [14, 5 and 0]
Pathloss (MBS-UE)	$128.1 + 37.6log_{10}[d(km)]$
Pathloss (PBS-UE)	$140.7 + 36.7log_{10}[d(km)]$
Pathloss (D2D)	$148 + 40log_{10}[d(km)]$
Shadowing [Cellular, D2D]	[10, 8] dB
Resource Allocation Scheduler	Proportional Fair
Traffic Model	Full Load
Noise Power density	-174 dBm/Hz
CRE and ABS	15 dB and 15/40

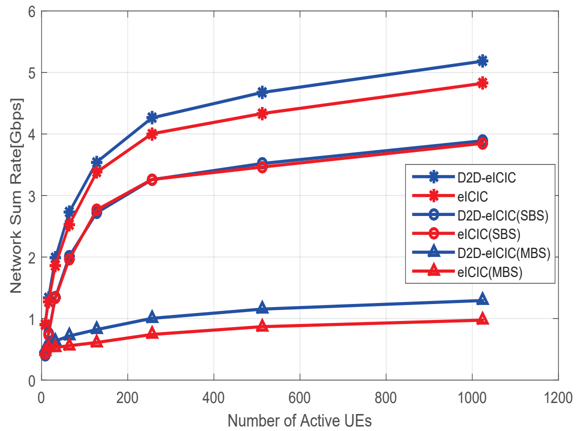

Fig. 6: Sum Rate vs Number of UEs

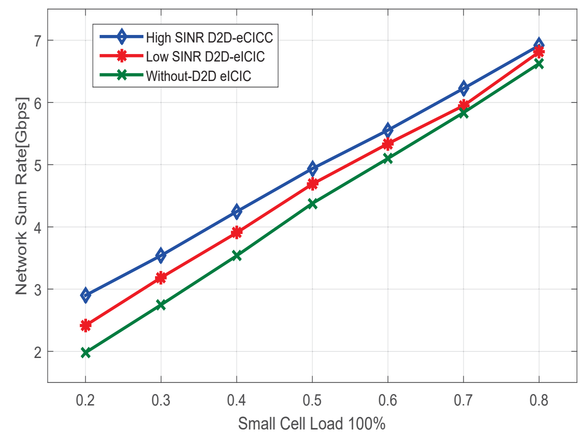

Fig. 7: Effect of the Relay Channel Rate on the performance of D2D-eICIC

users to establish a direct communication.

Finally, the rate of the relay channel that was given in (11) depends on the rate of the selected two hops. However, in order for the proposed D2D-eICIC algorithm to be more efficient the rate of the relay channel needs to be high. In Fig. 7 we show a comparison between two different cases of high and low SINR at the relay channel. We can see that the proposed D2D-eICIC scheme is performing better when the rate at the relay channel is high. However, even at low SINR at the relay channel we managed to achieve a higher sum-rate than that of eICIC without D2D communications using moderate traffic load of 50%.

VIII. Conclusions

In this work, we have investigated methods for improving the spectral efficiency performance of eICIC applied to HetNets. We considered allocating spectral resources to MUEs during ABS subframes to avoid the service degradation of the MBS when eICIC is applied. We proposed a heuristic algorithm called D2D-eICIC that uses D2D communications to assist in delivering the downlink data during ABS subframes to MUEs to overcome the transmission discontinuities during ABS subframes. We demonstrated that D2D-eICIC performance depends on the traffic load at the SBSs and on the relay channel conditions. The simulation of the network sum-rate showed that our technique outperformed the traditional eICIC and the baseline schemes at moderate traffic load conditions. For the future work, we plan to consider optimizing the relay selection to maximize the rate of the relay channel.

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