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Enhanced Cell Range Expansion and Radio Resource Allocation for a Better Traffic Offloading in HetNets

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Abstract Cell range expansion (CRE) is a promising solution to offload macrocells' traffic and improve the radio capacity in heterogeneous network (HetNet). On the other hand, enhanced inter-cell interference coordination (eICIC) techniques are introduced in HetNets to mitigate the severe interference caused between the small cells and the macrocell. In this paper, we present a novel application of the CRE coupled with a new time and frequency domain based eICIC technique. Our approach offers a dynamic radio resource allocation scheme which takes into account the number of femtocells inside the macrocell, the femtocells' loads and the macrocell load. First, we propose a so called FT-CRE scheme which alternates the transmission of the macrocell and the femtocells offering high traffic offloading. Then, a more elaborated scheme called enhanced FT-CRE (eFT-CRE) is presented. In this scheme, the need in traffic offloading is estimated so that time and frequency resources are allocated between the macrocell and the femtocells accordingly. The performance of both proposed FT-CRE and eFT-CRE schemes is evaluated through simulations. The results showed that when FT-CRE scheme is applied, the achieved throughput of the victim macro-users served by femtocells which apply the CRE is increased by 6 times as compared to a common application of CRE technique based on time domain multiplexing eICIC only. The outage probability of these victim macro-users is also significantly decreased. More importantly, the eFT-CRE scheme reveals more effective in terms of total achieved throughput in the system, the outage probability and energy efficiency at the macrocell.

Keywords HetNet · Cell range expansion · TDM-eICIC · Femtocell · Energy efficiency

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1 Introduction

1.1 Background and Related Work

Mobile data traffic continues to grow every day in an exponential way especially with the usage of smartphones, tablets, etc. Indoor services' demand is noticeably more important than outdoor services demand. Therefore, it is essential to improve the system radio capacity in indoor environment. The 3GPP has indeed introduced a new network topology called heterogeneous network (HetNet) for LTE-A system (Release 10). The HetNet consists of a mix of macro eNodeB (MeNB) and a variety of small size base stations such as pico eNodeB (PeNB) and home eNodeB (HeNB). The latter also called femtocell is a low power, low cost and short range transmitter as compared to the MeNB. Numerous benefits of using femtocells can be cited, for instance: they provide good indoor coverage, enhance radio link quality of indoor users, are able to offload data traffic from the MeNB, and consequently improve the network radio capacity [1].

In order to fully benefit from HetNet advantages, the problem of interference between femtocells and macrocells (cross-tier) and between femtocells (co-tier) should be solved [2]. Cross-tier interference problem should be particularly addressed. In fact, the macro-user equipment (MUE), which is attached to the MeNB and referred to as victim MUE in this paper, suffers from sever interference from the HeNB when the latter is located in its vicinity. Enhanced inter-cell interference coordination (eICIC) techniques have recently emerged as an effective mechanism to mitigate this kind of interference. They can be classified into three categories: time domain, frequency domain and power control [3].

In this paper, we investigate the time domain multiplexing eICIC (TDM-eICIC) in order to help the victim MUE avoid cross-tier interference. In TDM-eICIC, a time alternation between the HeNBs and the MeNB is used. Each base station type transmits on a different transmit time interval (TTI) which corresponds to the subframe duration. More precisely, when the MeNB transmits on a TTI, all HeNBs inside the macrocell are silent, and vise-versa [4]. On the other hand, cell range expansion (CRE) technique was introduced to allow a victim MUE to connect to a nearby HeNB [5, 6]. This technique expands the coverage area of the local HeNB by increasing its transmit power. In this case, the victim MUE becomes directly served by the HeNB and the MeNB is offloaded. In order to totally eliminate the cross-tier interference and achieve macrocell offloading, TDM-eICIC and CRE can be jointly applied in a HetNet. In fact, a victim MUE becomes attached to a nearby HeNB during the TTI in which the MeNB is silent. However, a more elaborated combination between TDM-eICIC and CRE is much needed in order to improve the bandwidth sharing, and so the system radio capacity in HetNets.

Several studies have addressed the application of TDM-eICIC and CRE in HetNets. Some of them (e.g. [7, 8]) have investigated the impact of the CRE range on the performance of a TDM-eICIC based HetNet. Others (e.g. [9–15]) have examined the number of the TTIs during which the MeNB should be silent. In [7], the authors proposed a TDM-eICIC approach based on a Lightly Loaded CCH transmission subframe. They analyzed the effect of various pico cell CRE values in order to reduce the interference level on the control channel (CCH channel). In [8], the authors proposed to dynamically vary the pico cell range in a TDM-eICIC based HetNets. The author introduced a utility function based on the cell load, and increased the pico cell range if pico cell utility is superior to the one of the MeNB. In [9], a TDM-eICIC resource partitioning is considered with pico cell CRE to improve cell edge throughput. The system performance is evaluated by changing the

almost blank sub-frame (ABSF) pattern and the CRE bias value. In [10], the authors proposed a cell planning model with TDM-eICIC in which only the MeNB can mute the subframe. The CRE is applied by the pico-eNBs during the muted subframes. The authors aimed at finding the minimum number of pico-eNBs such that a tradeoff between the number of muted subframes and MeNB's overload is achieved. In [11], the authors proposed a tracking procedure to mark and unmark the victim MUE. Based on communication between the MeNB, the victim MUEs and HeNBs, the MeNB triggers the ABSF mode at aggressor HeNBs and applies the scheduling such that the victim MUEs are served during these ABSFs. In [12], an approach called ABSF offsetting is proposed to assign a reduced ABSF blanking rate with an offset at aggressor HeNBs while keeping the optimal blanking rate at the MeNB. The authors used the multistage Nash bargaining in the context of optimal resource partitioning in order to perform the parameter selection for the ABSF offsetting. In [13], the authors extended the ABSF offsetting proposed in [12]. The idea is to propose the concept of virtual arbitrary blanking ABSF rates with no limitation of the blanking rate in both FDD and TDD modes. In [14], the authors determined the number and location of subframes that are to be blanked at each aggressor HeNB according to the number of victim and normal users. In [15], the authors studied the number of adequate ABSFs using tools from stochastic geometry and based on users' throughput requirements as well as base station placement.

On the other hand, energy efficiency has ultimately attracted much attention in order to improve power consumption in the network. Some contributions (e.g. [16–19]) have recently dealt with energy efficiency in HetNets. In [16], the authors gave some analysis in frequency time domain eICIC with different frequency reuse factors. In [17], the authors proposed a handover mechanism as a way to save the energy consumption. The idea is to connect the users of the picocell to its neighboring picocells and macrocell by using the remaining resource. In [18], the authors studied the impact of high deployment of picocells on the radio capacity in HetNets. In [19], the authors have studied the power consumption at both macro and pico cells regardless of the eICIC pattern deployed.

1.2 Our Contribution and Organization of the Paper

In this paper, we study the application of the CRE in a TDM-eICIC based HetNet. We investigate a new radio resource allocation scheme in which time and frequency sharing between the MeNB and the HeNBs dynamically varies according to the traffic offload of femtocells applying CRE. We aim at reducing the outage probability of victim MUEs and thus enhancing the radio capacity in the system. We also show that with our proposed scheme we largely improve the energy efficiency of the system.

As compared to the aforementioned contributions, we first use a common ABSF pattern in which the MeNB and some HeNBs' transmissions are alternated. A new bandwidth sharing between MeNB and HeNBs is proposed to enhance the victim MUEs quality of service. Then, we apply an adaptive number of the ABSFs to further enhance the system performance in terms of total achieved throughput in the system, the outage probability and energy consumption at the MeNB.

More precisely, the HeNBs are classified into two categories: Lo-HeNB and Ho-HeNB. The Lo-HeNBs are HeNBs with low traffic offload. This means that few victim MUEs (or some victim MUEs presenting low data rate demand) are situated around these HeNBs. Ho-HeNBs are HeNBs with high traffic offload which means that a large number of victim MUEs (or some victim MUEs with high data rate demand) is nearby these HeNBs and may be served when CRE is applied. Depending on its category, a HeNB is allowed or not to

transmit at the same TTI as the MeNB. The Lo-HeNBs jointly transmit with the MeNB at the same TTIs, whereas the Ho-HeNBs transmit at different TTIs. In the first proposed scheme, called FT-CRE, the TTIs of an LTE-A radio frame are equally partitioned between the MeNB and the Lo-HeNBs, and the Ho-HeNBs. In the second proposed scheme, called eFT-CRE, the TTIs are adaptively partitioned between the two sets in order to ensure a better application of the CRE.

Our paper is organized as follows. In Sect. 2, we give our system model and problem formulation. In Sect. 3, we present the limitation of the basic application of the CRE in TDM-eICIC based HetNets. In Sects. 4 and 5, we describe and analyze our proposed FT-CRE and eFT-CRE schemes respectively. Finally, Sect. 6 concludes this paper.

2 System Model and Problem Formulation

We consider a HetNet composed of one MeNB and F femtocells randomly distributed inside the macrocell. We assume that the MeNB is centered in the macrocell area and serves the whole macrocell as one sector. Each femtocell is covered by one HeNB. The macrocell and the femtocell have a coverage radius of R_M and R_F respectively ($R_F \ll R_M$). Similarly, the MeNB and the HeNBs have a total available transmit power P_M^{tot} and P_F^{tot} respectively ($P_F^{tot} \ll P_M^{tot}$). In order to expand its coverage area to R_F^{CRE} ($R_F < R_F^{CRE} \ll R_M$), the HeNB increases its transmit power to P_F^{CRE} such that $P_F^{tot} < P_F^{CRE} \ll P_M^{tot}$. The MeNB and the HeNBs can operate on both silent and active mode.

Each HeNB serves U femto-users uniformly distributed in the femtocell and operates in hybrid access mode which enables it to serve some macro-users in its vicinity. So, when a HeNB expands its coverage area by increasing its transmit power, the nearby victim MUE can be served by this HeNB (Fig. 1). As a matter of fact, these victim MUEs have every thing to gain from the application of the CRE as they become served by a closer 4G transmitter. We assume that all HeNBs inside the macrocell are not overloaded and have thus sufficient frequency bandwidth to serve some victim MUEs.

According to Fig. 1, when a HeNB partially shares the spectrum with the MeNB, the victim MUE suffers from severe cross-tier interference caused by the neighboring HeNB. On the other hand, users served by the HeNB also experience strong downlink cross-tier
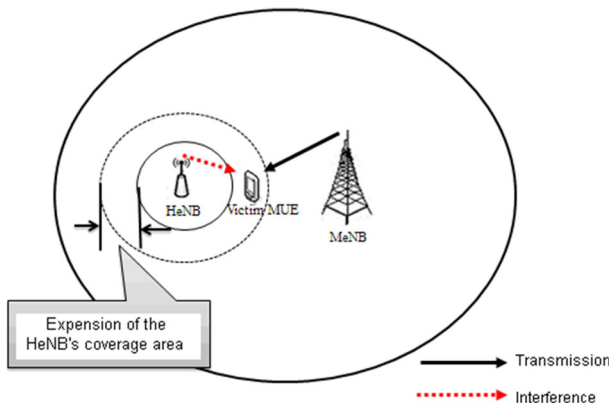

Fig. 1 System model

interference from the MeNB as the latter transmits higher power than the HeNB. Therefore, CRE technique is actually useful for the victim MUEs only if it is applied in either TDM or FDM (frequency division multiplexing) modes. In this paper, we investigate an effective way to apply CRE in order to enhance victim MUEs' throughput and system radio capacity. Hereafter, we present a typical CRE technique in a TDM based HetNet, then we propose a more elaborated scheme in which TDM and FDM modes are jointly used with CRE technique. We define the outage probability P_{out} as the probability that a victim MUE u cannot achieve his required throughput:

$$P_{out} = \Pr\{u/r_u < r_u^0\} \tag{1}$$

where r_u and r_u^0 are respectively the achieved and the required throughput of a victim MUE u.

Since we aim at enhancing the quality of service of the victim MUEs and the system radio capacity, our optimization problem is thus given by:

$$\min P_{out}$$
$$\text{Subject to: } B_{vM} \leq B_{tot} - B_F \tag{2}$$

where B_{vM} is the bandwidth allocated by all HeNBs applying CRE to the served nearby victim MUEs, B_F is the total bandwidth allocated to the HeNBs to their femto-users, and B_{tot} is the total available bandwidth in the system.

3 Basic T-CRE Scheme for HetNets

In this section, we present a basic application of CRE technique in a TDM-eICIC based HetNet. We will consider this model, referred to as T-CRE scheme in our paper, as a reference for the evaluation of our proposed dynamic CRE application in the following section.

3.1 Description of the T-CRE Scheme

When a victim MUE is connected to a neighboring HeNB by CRE, it suffers from important interference from the MeNB if both HeNB and MeNB operate on the same frequency bandwidth. Therefore, CRE combined with TDM-eICIC comes as a solution to cancel this cross-tier interference. In fact, in time domain technique, transmissions of MeNB and HeNB are organized in time in such a way that when one is in state of transmitting data the other is in a state of silence [4]. More precisely, the time duration of
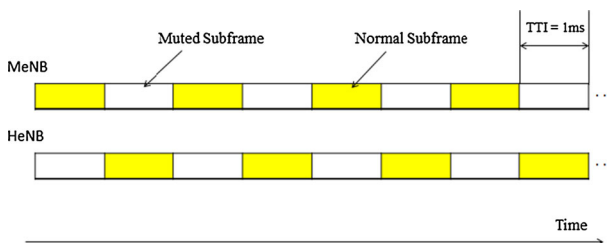

Fig. 2 Considered TDM-eICIC pattern

silence or data transmission is the length of one TTI which corresponds to one subframe. When a base station, either MeNB or HeNB, is in a silent state, it transmits a muted subframe, which contains no traffic data. These subframes are generally called almost blanc subframes (ABSF) [20]. In our basic T-CRE scheme, we assume that the MeNB transmits in the odd TTIs of a frame while all HeNBs transmit in the even TTIs (Fig. 2). We also assume that during the even TTIs, all HeNBs systematically apply a CRE and serve some victim MUEs in their vicinity. We consider that the bandwidths allocated to the HeNBs are not overlapped and that all HeNBs are not overloaded either. Hence, they have enough frequency bandwidth to serve some victim MUEs. The latter are served one by one starting by those requiring the lowest data rate.

The received signal-to-interference and noise ratio ($SINR_u$) of a victim MUE u at the even TTI according to our T-CRE scheme is expressed by:

$$SINR_u = \frac{p_{f,u}/L_{f,u}}{N_0} \tag{3}$$

where $p_{f,u}$ is the transmit power from the serving HeNB f to the victim user u, $L_{f,u}$ is the propagation channel gain which includes pathloss and shadowing from the serving HeNB f to the victim user u, and N_0 is the thermal noise. We note that since the MeNB is silent during the even TTI and the HeNBs transmit over separate bandwidths, the victim MU undergoes no interference.

Consequently, the achieved throughput r_u of the victim MUE u is given by:

$$r_u = w_u \log(1 + SINR_u) \tag{4}$$

where w_u is the allocated bandwidth from the serving HeNB to the victim MUE u.

3.2 Limitations of the T-CRE Scheme

In this section, we point out the benefit of the CRE application in a HetNet, but at the same time we show the limitation of the basic T-CRE scheme. To do so, we define the following performance metrics:

- TAT: the Total Additive Throughput which represents the sum of the achieved data rates of victim MEs served by all HeNBs in the macrocell during the even TTIs,
- P_{out}: the outage probability (Eq. 1) which represents the probability that a victim MUE couldn't meet its throughput requirements during the even TTIs.

Table 1 Simulations parameters

Parameter	Value
MeNB Radius (m)	500
HeNB Radius (m)	50
HeNB Radius with CRE (m)	70
Total available bandwidth B_{tot} (MHz)	20
MeNB transmit power P_M (W)	20
HeNB transmit power P_F (W)	0.125
HeNB transmit power with CRE P_F^{CRE} (W)	0.175
Number of TTIs per frame	10

We suppose that the total available bandwidth is equal to 20 MHz and that this bandwidth is equally subdivided between the different HeNBs during the even TTIs. We also assume that all MUEs are uniformly distributed in the macrocell and that three HeNBs coexist inside this macrocell ($F = 3$). The HeNBs have random positions and can serve up to 5 femto-users ($1 \leq U \leq 5$). Other simulations parameters are summarized in Table 1. Simulation results presented hereafter are the average of the performance metrics obtained with 1000 snapshots.

Figure 3 depicts the TAT per even TTI versus MeNB's load in case of using the "TDM-eICIC without CRE" and in case of using the "TDM-eICIC with CRE". In the first case, no CRE is applied by the HeNBs during the even TTI, whereas in the second case, the victim MEs are allowed to connect to the nearby HeNBs according to the T-CRE scheme. We observe that of course, without CRE, no additive data rate is achieved by the victim MUEs. But thanks to the T-CRE scheme and the application of the CRE during the even TTIs, the victim MEs can indeed enhance their achieved throughput. For instance, if the required MeNB's load is around 200 Mbps, the HeNBs can provide up to 48 Mbps. As the required MeNB's load increases, the HeNBs keeps satisfying the victim MUEs data requirements until bandwidth is no longer available at these HeNBs. At this point, the total additive throughput remains constant with the increase of the MeNB's load.

Figure 4 illustrates the outage probability of the victim MUEs P_{out} per even TTI versus MeNB's load in case of using the "TDM-eICIC without CRE" and in case of using the "TDM-eICIC with CRE". It is obvious that this outage probability of victim MUEs is equal to 100 % in the first case since no victim MUE can take advantage of the CRE technique during the even TTI. However, thanks to the application of the CRE by the different HeNBs during
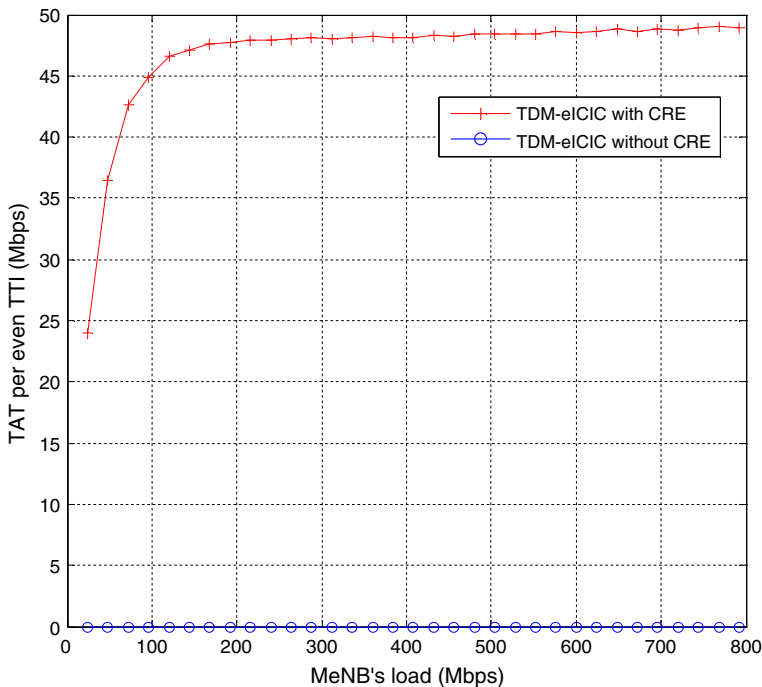

Fig. 3 Total additive throughput versus MeNB's load in "TDM-eICIC without CRE" and in "TDM-eICIC with CRE" cases
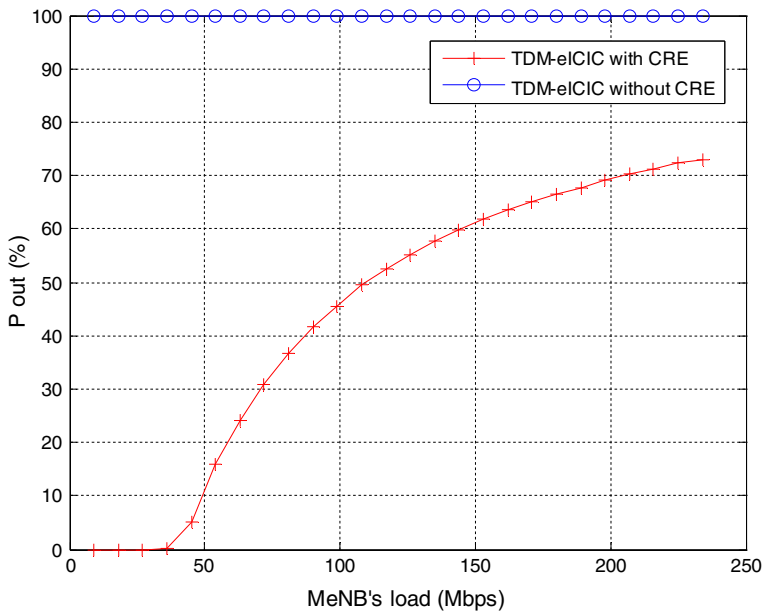
Fig. 4 Outage probability versus MeNB's load in "TDM-eICIC without CRE" and in "TDM-eICIC with CRE" cases

the even TTI, the victim MEs can improve their achieved throughput and therefore meet their QoS requirements. When the required MeNB's load is low, CRE helps satisfy all victim MUEs demands and the outage probability indeed is null. As the required MeNB's load increases, this outage probability increases as well since the HeNBs have limited bandwidths, but it is far lower than in case of no CRE is applied by the HeNBs.

The limitation of the available bandwidth at the HeNBs to serve more victim MUEs during the even TTIs prevents a further reduction of the outage probability and improvement of the victim MUEs' quality of service. In the next sections, we build a more elaborated time and frequency sharing between the MeNB and the HeNBs in order to intelligently partition these resources and enhance the system performance.

4 The Proposed FT-CRE Scheme

Hereafter, we propose a new dynamic approach in which CRE is jointly coupled with TDM-eICIC and FDM-eICIC in order to further enhance the victim MUEs' throughputs and the system outage probability.

4.1 Description of the FT-CRE Scheme

In practice, macro-users are gathered into different hot-spots inside one macrocell. The basic idea of our dynamic approach is to allow some HeNBs, which have few or no victim MUEs in their vicinities, to transmit during the odd TTIs simultaneously with the MeNB.

This would in fact decrease the number of HeNBs sharing the total available bandwidth during the even TTIs and allow them to serve more victim MUEs around.

Therefore, we classify the HeNBs into two categories: Lo-HeNB and Ho-HeNB. We assume that the MeNB and the different HeNBs exchange their information on the S1 interface through the Core Network and a DSL Gateway. Another alternative, which consists of establishing a direct air interface between the MeNB and the HeNBs, could also be considered to ensure this exchange as suggested in [21]. According to the information collected at the MeNB from the served macro-users, and forwarded to the HeNBs, each HeNB can in fact be aware of the victim MUEs in its vicinity and their required throughputs. Consequently, HeNBs with no victim MUE around or HeNBs which are surrounded by victim MUEs requiring slow data rates are called Lo-HeNBs. On the other hand, HeNBs which are surrounded by victim MUEs requiring fast data rates are called Ho-HeNBs.

Let η_x the category index of a given category x of HeNBs defined as follows:

$$\eta_x = \frac{\sum_{i=1}^{N_x} \left(B_{vM}^i + B_F^i \right)}{B} \tag{5}$$

where N_x is the cardinal of the HeNBs' set from the category x, B_{vM}^i is the bandwidth allocated by the HeNB i from the category x to the served nearby victim MUEs, B_F^i is the bandwidth allocated by the HeNB i from the category x to its femto-users, and B is the remaining total bandwidth after the non victim MUEs are served. Therefore, the
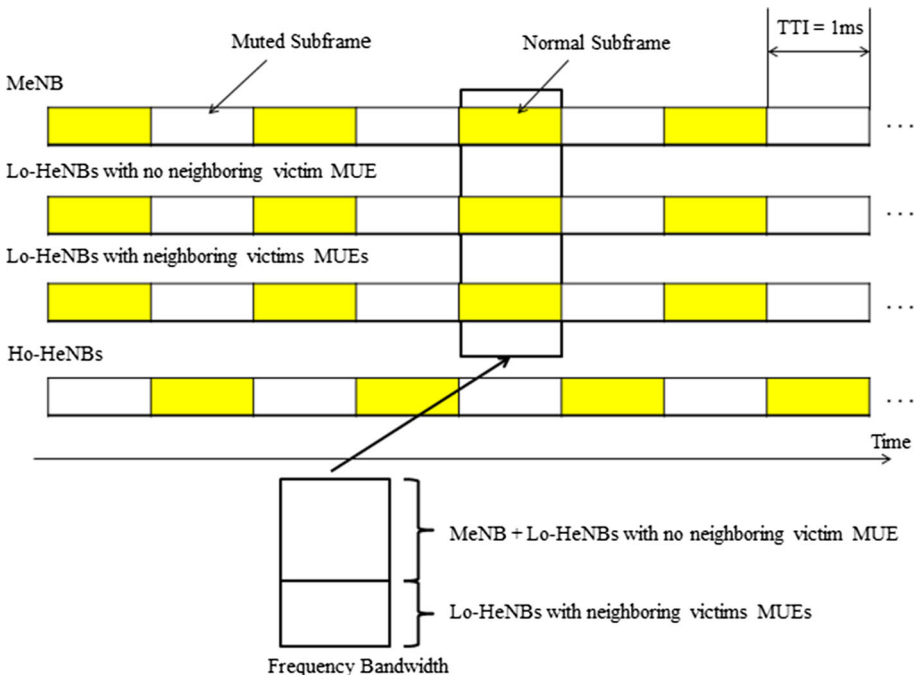

Fig. 5 Proposed FT-CRE scheme

Lo-HeNBs' category verifies the condition $\eta_{Lo\text{-}HeNBs} < 1$, whereas the Ho-HeNBs' category verifies the condition $\eta_{Ho\text{-}HeNBs} > 1$.

The first group of HeNBs (i.e. Lo-HeNBs) is allowed to transmit during the odd TTIs simultaneously with the MeNB; whereas the second group of HeNBs operates on the even TTIs, as shown in Fig. 5. Since the Lo-HeNBs share the total available bandwidth with the MeNB during the odd TTIs, we apply a FDM multiplexing between the MeNB and the Lo-HeNBs at these subframes. More precisely, Lo-HeNBs with no neighboring victim MUs transmit on the same frequencies than the MeNB. However, Lo-HeNBs having victim MUE in their vicinities transmit on a separate frequency bandwidth (Fig. 5). In fact, in this way, victim MUEs don't suffer from interference caused by the MeNB. Note that this is an easy FDM pattern which is suggested here during the odd TTI to ensure bandwidth sharing between the MeNB and the Lo-HeNBs. The purpose is in fact to mix TDM and FDM-eICIC pattern jointly with CRE technique to further enhance the system performance. But, other FDM-eICIC techniques coupled with CRE can also be applied during the odd TTIs (e.g. [22, 23]). Table 2 gives more details about the classification of the HeNBs into Lo-HeNBs and Ho-eNBs.

On the other hand, both Lo-HeNB and Ho-HeNBs apply CRE whenever they have victim MUEs in their vicinities. In our proposed algorithm, referred to as FT-CRE scheme, the HeNBs serves the victim MUEs one by one starting by the victim MUE requiring the lowest bandwidth.

Since we study the application of CRE in TDM-eICIC based HetNets, we estimate the system performance metrics only during the even TTIs. The received $SINR_u$ of a victim MUE u at the even TTI when the FT-CRE is applied is expressed by the same Eq. (3). Similarly, the achieved throughput of the victim MUE u is given by the Eq. (4). In fact, according to our proposed frequency and time division based eICIC scheme, the victim MUE u is served by one HeNB and does not suffer from interference from other HeNBs inside the considered MeNB during the even TTI.

Table 2 Proposed HeNBS' classification

Input: victim and non victim MUEs' sets and their required throughputs
Output: Lo-HeNBs' and Ho-HeNBs sets
1: Compute B;
2: $N_{Lo\text{-}HeNBs} = 0$; $N_{Ho\text{-}HeNBs} = 0$;
3: **For** each HeNB i
4:　　　estimate B_F^i and B_{vM}^i ;
5:　　　compute $\eta_{Lo-HeNBs}$
6:　　　if $\eta_{Lo-HeNBs} < 1$;
7:　　　then
8:　　　　Lo-HeNBs $\leftarrow i$;
9:　　　　increment $N_{Lo\text{-}HeNBs}$
10:　　　else
11:　　　　Ho-HeNBs $\leftarrow i$;
12:　　　　increment $N_{Ho\text{-}HeNBs}$
13: **End**

4.2 Evaluation of the FT-CRE Scheme

In this section, simulations are conducted using the system parameters in Table 1 and assuming that the MUEs are gathered in hotspots inside the macrocell. Variable number of HeNBs is also considered.

Figure 6 depicts the TAT per even TTI versus MeNB's load when T-CRE and FT-CRE schemes are applied. We remind that this TAT is achieved during the even TTIs as we basically evaluate the effectiveness of CRE application in TDM-eICIC based HetNets. We observe that for a given number of HeNBs in the system, the FT-CRE scheme outperforms the T-CRE scheme. This is due to the fact that with the FT-CRE scheme, the Lo-HeNBs are not activated during the even TTIs and so no bandwidth is allocated to them. They can transmit on the Odd-TTIs as long as the MeNB has some available bandwidth (i.e. the MeNB is not overloaded). More importantly, we notice that the FT-CRE scheme becomes more attractive when the number of HeNBs increases in the system. For instance, for a MeNB's load equal to 400 Mbps, the FT-CRE scheme achieves a value of TAT 5 Mbps more than the T-CRE for a number of 4 HeNBs inside the macrocell ($F = 4$), whereas this difference is about 28 Mbps for $F = 8$.

However, the overall TAT decreases with the increase of the number F of HeNBs inside the macrocell in case of low MeNB's load (Fig. 7) as well as in case of high MeNB's load (Fig. 8). In fact, as the femtocell load becomes more important, few HeNBs can share the remaining bandwidth during the odd TTIs. A small bandwidth becomes thus available for the victim MUEs during the even TTIs. The same thing is observed when both the F and the MeNB's load increase. Although the overall TAT decreases when F increases, the application of the proposed FT-CRE scheme largely improves the system radio capacity as compared to the T-CRE scheme, as an additional total throughput of about 6 times can be reached with $F = 8$ in both cases low and high MeNB's load.
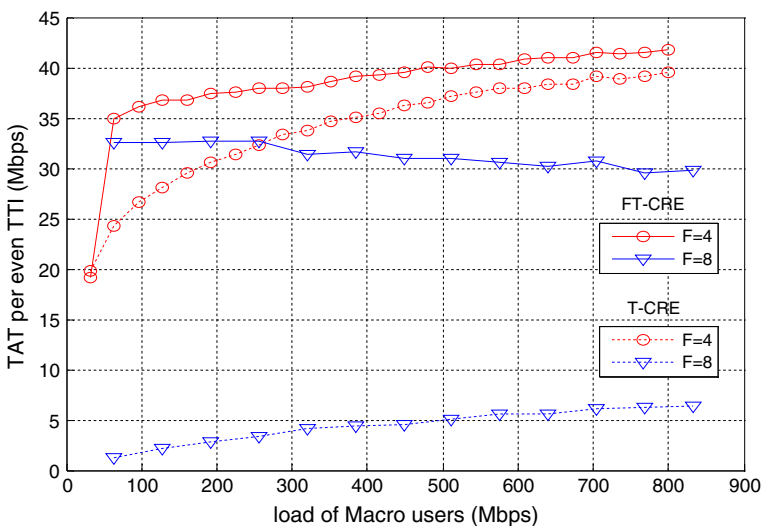

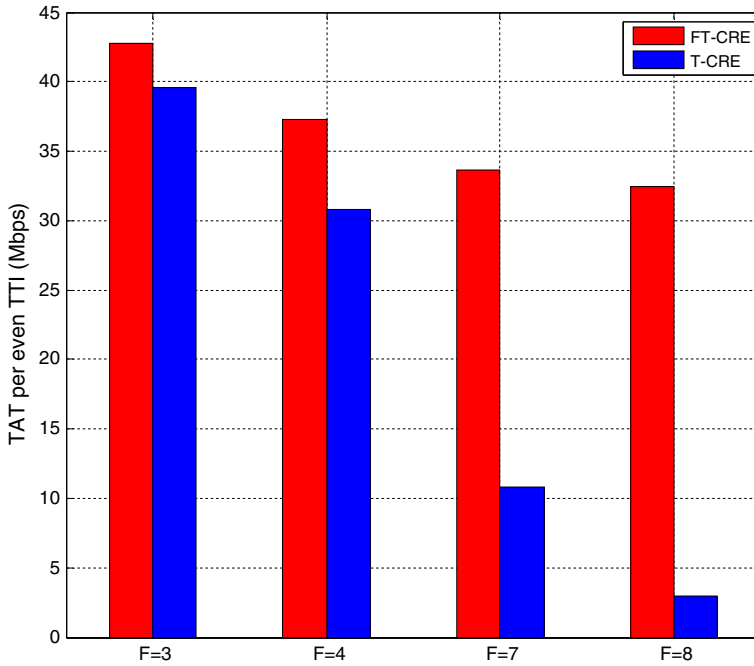**Fig. 6** Total additive throughput versus MeNB's load for T-CRE and FT-CRE schemes ($F = 4$ and $F = 8$)

Fig. 7 Total additive throughput versus number of HeNBs for low MeNB's load (200 Mbps)
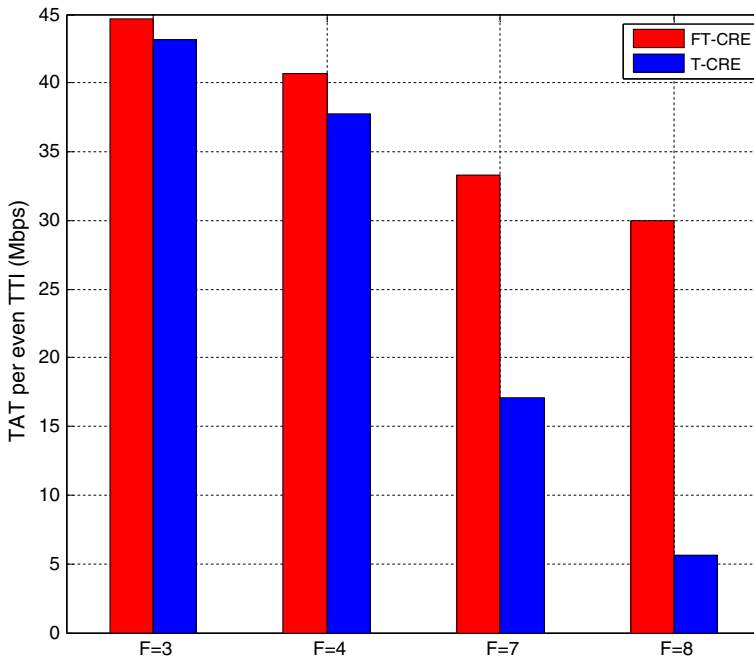

Fig. 8 Total additive throughput versus number of HeNBs for high MeNB's load (600 Mbps)

Finally and similarly to the T-CRE scheme, the Ho-HeNBs keep serving the victim MUEs until all their allocated bandwidths are consumed. The TAT thus is reaches a certain level from a certain MeNB's load, equal to 600 Mbps according to Fig. 9.

Figure 10 illustrates the outage probability of the victim MUEs per even TTI versus MeNB's load for both T-CRE and FT-CRE schemes. It shows that the FT-CRE scheme outperforms the T-CRE scheme especially for low loaded MeNB. In fact, the smaller the MeNB's load is, the more HeNBs can transmit during the Odd-TTIs and the less the unsatisfied victim MUEs are. However, when F increases, fewer victim MUEs could benefit from the CRE as less bandwidth is available in the system.

5 The Enhanced FT-CRE Scheme

In the former proposed FT-CRE scheme, we applied a common ABSF pattern in which the activation of femtocells and macrocell is ruled using a fixed number of muted (or blanked) subframes. This new approach significantly improved the throughput of the victim MUEs served by femtocells applying the CRE and thus reduced the outage probability of these victim MUEs, as compared to the basic T-CRE scheme. In order to fully benefit from the application of CRE, we investigate the appropriate number of ABSF allocated to both MeNB and HeNBs in the proposed FT-CRE scheme. Therefore, in this section we present a new solution called enhanced FT-CRE (eFT-CRE) based on the former FT-CRE scheme.
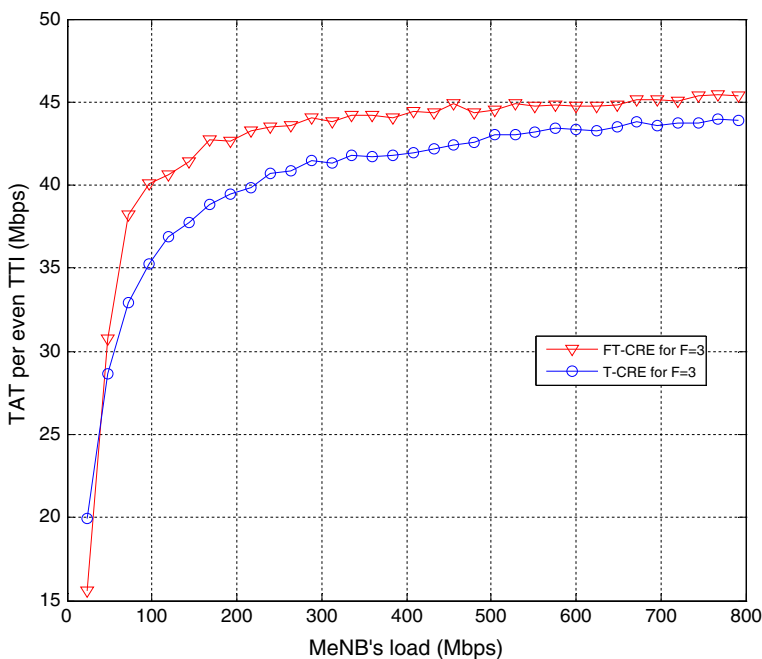

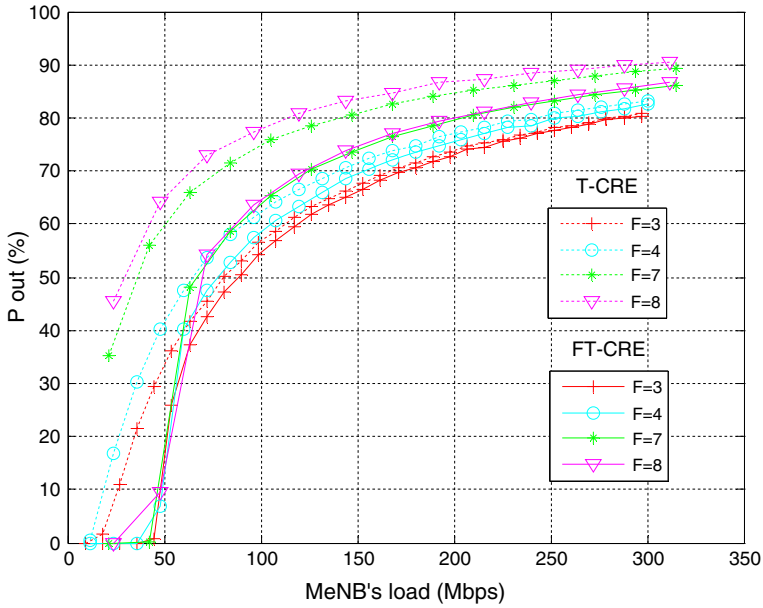**Fig. 9** Total additive throughput versus MeNB's load for T-CRE and FT-CRE schemes (F = 3)

Fig. 10 Outage probability of victim MUEs versus MeNB's load for T-CRE and FT-CRE schemes
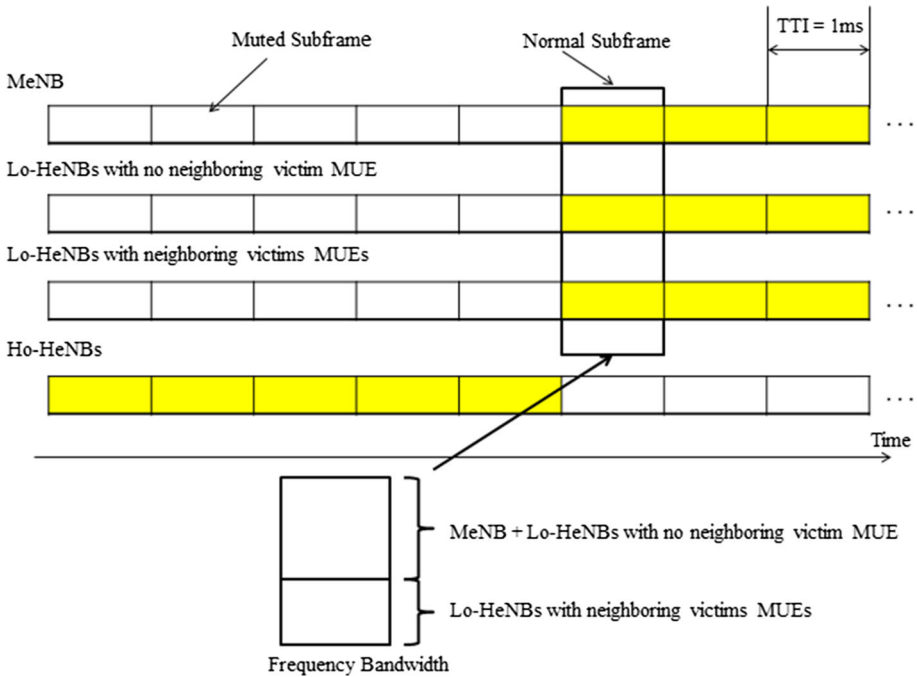

Fig. 11 Proposed eFT-CRE scheme

5.1 Description of the eFT-CRE Scheme

Instead of activating the Lo-HeNBs at the odd TTIs and the Ho-HeNBs at the even TTIs, in the proposed eFT-CRE scheme, the number of the ABSF for both MeNB and HeNBs is adaptively determined according to their bandwidth needs. First, the number of ABSF assigned to the Ho-HeNBs is estimated. Then, the number of ABSF assigned to both MeNB and Lo-eNBs is deduced.

After classifying the HeNBs into Lo-HeNBs and Ho-HeNBs, we determine the total bandwidth required by the Ho-HeNBs during a LTE-A radio frame in order to meet their femto-users throughputs as well as the nearby victim MUEs' throughputs. Assuming that the Ho-HeNBs can transmit at most during 9 TTIs over the 10 TTIs of a LTE-A radio frame, the number $ABSF_{Ho}$ of the ABSF assigned to the Ho-HeNBs is hence deduced according to the following equation:

$$ABSF_{Ho} = \begin{cases} 10 - \lceil W_{Ho}/W_{TTI} \rceil & if \ \lceil W_{Ho}/W_{TTI} \rceil \leq 9 \\ 1 & otherwise \end{cases} \quad (6)$$

where W_{TTI} is the total available bandwidth on one TTI. Consequently, the number $ABSF_{Lo-M}$ of the ABSF assigned to both the MeNB and the Lo-HeNBs is equal to:

$$ABSF_{Lo-M} = 10 - ABSF_{Ho} \quad (7)$$

Figure 11 illustrates the time and frequency multiplexing between the MeNB and Lo-HeNBs on one side and the Ho-HeNBs on the other side of the proposed eFT-CRE scheme.

5.2 Evaluation of the eFT-CRE Scheme

In this section, we evaluate the performance of the proposed eFT-CRE scheme by comparing it to the simulations results of the previous FT-CRE and T-CRE schemes. We aim at evaluating the performance in terms of the following metrics:

- AvMUE_Thr: the average throughput per victim MUE which represents the average of the throughputs of victim MUEs' that are served by both Lo-HeNBs and Ho-HeNBs during a LTE-A radio frame,
- P_{out}: the outage probability (Eq. 1) which represents the probability that any MUE in the system couldn't meet his throughput requirements during a LTE-A radio frame,
- ATT: the Achieved Total Throughput which is the sum of the achieved throughput of all MUEs, those directly served by the MeNB and those served by the HeNBs applying the CRE,
- *EE*: the Energy Efficiency which reflects the energy consumption at the macrocell and is expressed in Mbps/W. It is calculated by dividing the achieved total throughput of all MUEs in the macrocell on a radio LTE-A radio frame by the total power consumed to serve these MUEs (by the MeNB as well as by some HeNBs within the macrocell):

$$EE = \frac{ATT}{(P_M + P_M^{circuit}) + \sum_{f=1}^{F_M} \left(P_f + P_f^{circuit} \right)} \quad (8)$$

where P_M is the total MeNB's transmit power, $P_M^{circuit}$ is the circuit power consumed by the MeNB, F_M is total number of HeNBs applying CRE, P_f is the total transmit power of the HeNB f which is applying CRE and $P_f^{circuit}$ is the circuit power consumed by this HeNB.

We consider the same simulation parameters and assumptions as in the previous section and assume the coexistence of four HeNBs within the coverage area of the macrocell ($F = 4$).

Figure 12 depicts the AvMUE_Thr versus the MeNB's load when the T-CRE, FT-CRE and eFT-CRE schemes are applied. It shows that the eFT-CRE scheme considerably enhances the average throughput per victim MUE as compared to the FT-CRE scheme. For instance, for a total load of 200 Mbps at the MeNB, the average throughput of a victim MUE reaches 4 Mbps when the eFT-CRE is applied, whereas it only reaches 1.5 Mbps when FT-CRE scheme is used. With the FT-CRE scheme, the average victim MUE throughput severely decreases with the increase of the MeNB's load. This is because of the limitation of the bandwidth allocated to each group Lo-HeNBs and Ho-HeNBs. However, when the eFT-CRE scheme is applied, the ABSF are assigned to the HeNBs adaptively according to the traffic offload they offer. Therefore, more radio resources are allocated to the victim MUEs and thus the average victim MUE throughput is improved as compared to the FT-CRE scheme's case. Similarly, with the T-CRE scheme, the AvMUE_Thr is much lower since fewer resources are available at the HeNBs to make efficient traffic offloading.

Figure 13 illustrates the outage probability of all MUEs in the system versus the MeNB's load when the T-CRE, FT-CRE and eFT-CRE schemes are applied. As more radio resources are allocated to the Ho-HeNBs so that they achieve a more efficient offloading, a larger number of victim MUEs can meet their quality of service requirement. Moreover, since the MUEs are gathered in hot-spots in the macrocell coverage area, they are likely to be closer to some HeNBs and so it would be beneficial to take advantage of a range expansion of these 4G transmitter. Consequently, the outage probability of all MUEs is significantly decreased when the eFT-CRE is applied especially for a high loaded MeNB. For instance, for a MeNB's load equal to 500 Mbps, the outage probability is
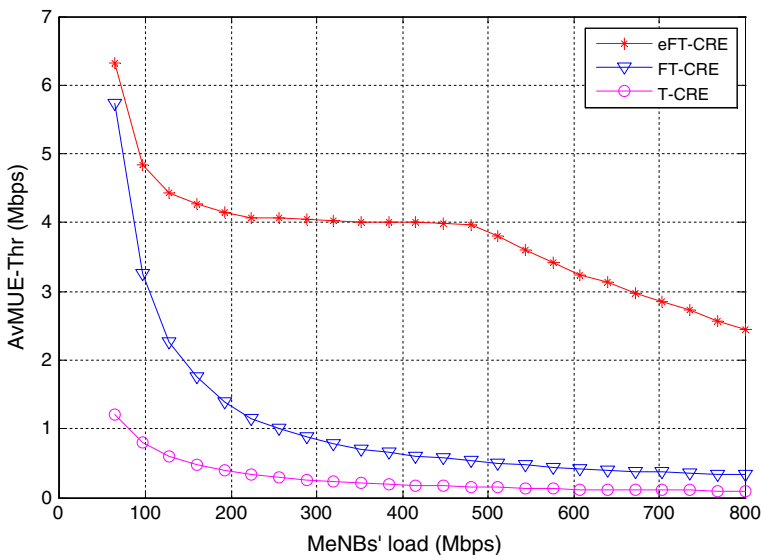

Fig. 12 Average throughput per victim MUE versus MeNB's load for T-CRE, FT-CRE and eFT-CRE schemes ($F = 4$)
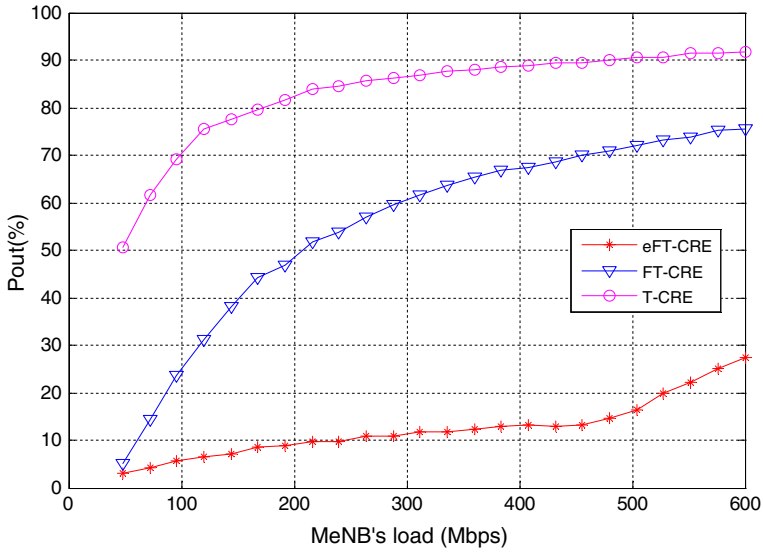
Fig. 13 Outage probability of all MUEs versus MeNB's load for T-CRE, FT-CRE and eFT-CRE schemes ($F = 4$)
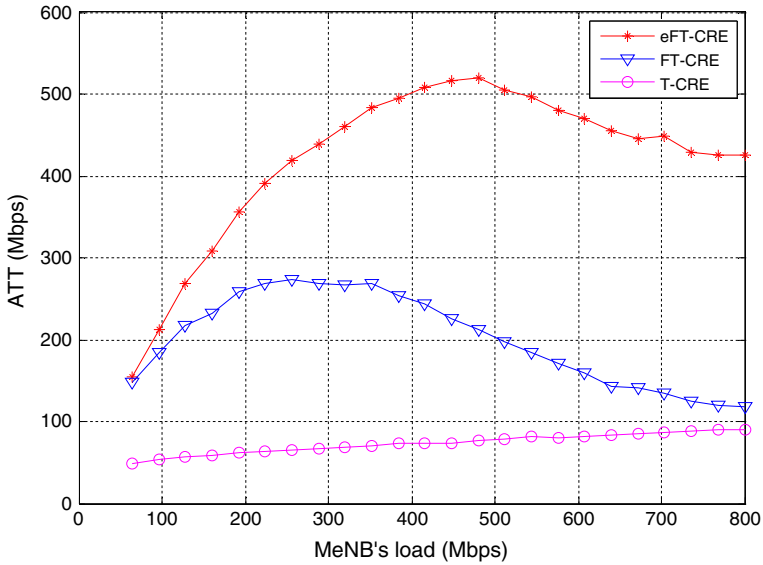

Fig. 14 Achieved total throughput of the MUEs versus MeNB's load for T-CRE, FT-CRE and eFT-CRE schemes ($F = 4$)

reduced of more than 70 % as compared to the FT-CRE scheme and about 80 % as compared to the T-CRE scheme.

Figure 14 depicts the ATT versus the MeNBs' load when the T-CRE, FT-CRE and eFT-CRE schemes are applied. It shows that system radio capacity is largely enhanced when the

eFT-CRE scheme is applied as compared to the case when FT-CRE and T-CRE schemes are used. This improvement reaches 3 and 5 times respectively, especially when the macrocell is highly loaded as the eFT-CRE scheme offers a more suitable and efficient traffic offloading. It can be also noticed that both schemes that when the MeNB's load goes higher, the ATT tends to decrease because of the lack of the radio resources in the system.

So far, we have shown that our proposed schemes significantly improve the radio capacity. It is also important to verify that this increase is energy-efficient. Let Ec_M be the energy consumption Ec_M of the MeNB during a LTE-A radio frame. Ec_M is expressed in Joule as:

$$Ec_M = P_M \times (10 - ABSF_{Lo-M}) \qquad (9)$$

Figure 15 depicts the energy consumption at the MeNB versus the MeNB's load for the T-CRE, FT-CRE and eFT-CRE schemes. It shows that the power is indeed considerably saved when eFT-CRE scheme is applied because of the adaptive allocated ABSF during a LTE-A radio frame. However, with both T-CRE and FT-CRE schemes, this power remains constant as the MeNB transmit every two TTIs whatever the load in the macrocell. This is also due to the fact that the HeNBs are not able to offer higher traffic offloading. In fact, when eFT-CRE scheme is applied the $ABSF_{Ho}$ is decreased if the MeNB's load increases to allow the Ho-HeNBs serve more efficiently the nearby victim MUEs. Moreover, Fig. 16 depicts the energy efficiency EE versus the MeNB's load when the T-CRE, FT-CRE and eFT-CRE schemes are applied. We deduce that not only power is saved at the MeNBs but also the energy efficiency is enhanced when the eFT-CRE scheme is applied. For instance, Fig. 16 shows that for a MeNB's load equal to 600 Mbps, the energy efficiency is
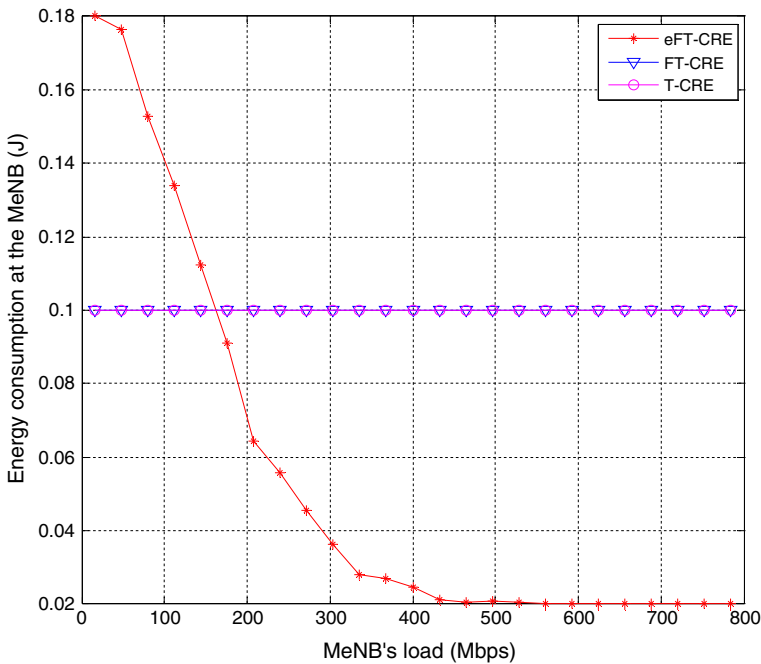

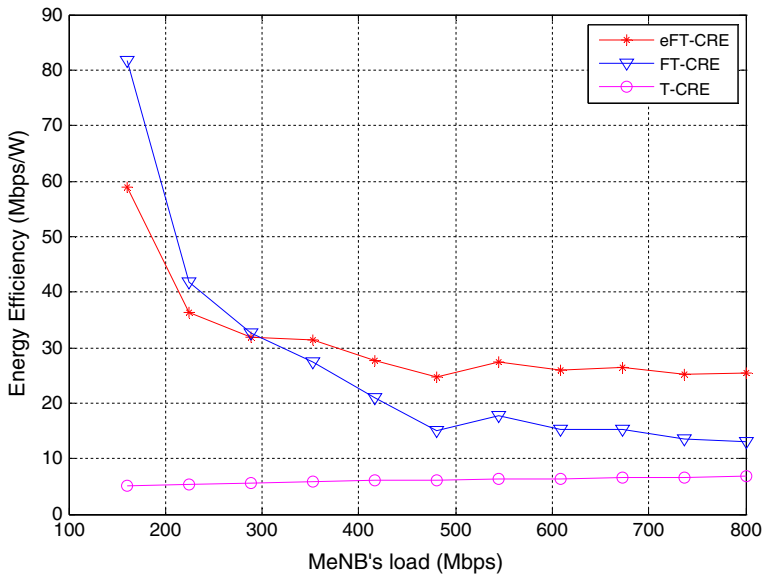Fig. 15 Energy consumption at the MeNB versus MeNB's load for T-CRE, FT-CRE and eFT-CRE schemes (F = 4)

Fig. 16 Energy efficiency versus MeNB's load for T-CRE, FT-CRE and eFT-CRE schemes ($F = 4$)

increased by 1.5 times and by 3.5 times as compared to the FT-CRE and the T-CRE schemes respectively. This results points out the importance of applying an adaptive traffic offloading, such as the proposed eFT-CRE scheme, in order to take advantage of the presence of low power transmitter in the HetNet environment and intelligently balance the radio resource allocation between the MeNB and the HeNBs.

6 Conclusions

In this paper, we proposed a new spectrum sharing scheme between MeNB and HeNBs in HetNets. Aiming at efficiently using the CRE and enhancing the system radio capacity, we've studied CRE technique in TDM-eICIC pattern, then in a combined time and frequency eICIC pattern.

In a first part of the paper, the HeNBs are classified into Lo-HeNBs and Ho-HeNBs according to the traffic offload they can ensure for the macrocell. The Lo-HeNBs jointly transmit with the MeNB at the same TTIs, whereas the Ho-HeNBs operate at different TTIs using a preset ABSF pattern. We showed that with this proposed FT-CRE scheme, a considerable number of victim MUEs can benefit from the presence of closer 4G transmitters. We proved that an important additional throughput can be achieved as compared to the basic T-CRE scheme.

In a second part, we have adjusted the number of ABSF assigned to each of the previous HeNBs' groups according to the total traffic to offload. This proposed approach called eFT-CRE proved to be more effective than the FT-CRE scheme in terms of radio capacity since the outage probability can be reduced by 70 % and the achieved total throughput is increased by 3 times. More importantly, the eFT-CRE reveals much more energy efficient which could encourage the operators to load off the macrocell traffic more effectively.

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