

# Energy Efficiency of Combined DPS and JT CoMP Technique in Downlink LTE-A Cellular Networks

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**Abstract**—Coordinated multi-point (CoMP) transmission introduced by long-term evolution-advanced (LTE-A) cellular systems has shown great promise for improving network spectral efficiency (SE). On the other hand, the ever increasing energy consumption in cellular systems has emerged as a major concern for the network operators. This paper proposes a novel CoMP technique for the downlink of two-tier heterogeneous LTE-A cellular networks and investigates its energy efficiency (EE) performance. The proposed CoMP technique combines both dynamic point selection (DPS) and joint transmission (JT) CoMP schemes for improving network SE. Thus, under the proposed CoMP technique, multiple transmitting base stations (BSs) selected dynamically from the available high-power macrocells and low-power small cells are coordinated for jointly serving a user. Various spatial distributions of small cells in the macrocell coverage area are considered. A Poisson distributed hard core point process (HCPP) is also used for maintaining a minimum distance between any two of the small cells. Extensive simulations are carried out for evaluating the EE performance of cellular networks deployed integrating the proposed CoMP technique. Network performance is also compared with that of non-CoMP, only JT and only DPS transmission scheme based cellular networks.

**Index Terms**—energy efficiency; CoMP; dynamic point selection; joint transmission; LTE-A

## I. INTRODUCTION

With the rise of new generation user terminals (e.g., smartphones), the ubiquitous availability of Internet access and the diverse multimedia applications are currently driving an explosive growth in cellular network data traffic. The corresponding ever-growing energy utilization has economic as well as environmental implications leading to higher network operating cost and deteriorating global warming phenomenon respectively [1]. Various recent studies reveal that the information and communication technology (ICT) industry including cellular networks contributes to about 2% of global carbon dioxide emissions, the same amount that the aviation industry produces [2]. Therefore, energy efficiency (EE) is being considered as one of the major performance indicators for planning and operating modern day cellular networks.

On the other hand, coordinated multi-point (CoMP) transmission technique is one of the key features introduced by third generation partnership project (3GPP) for both downlink

and uplink of long-term evolution-advanced (LTE-A) cellular systems [3]. Investigations on CoMP techniques have demonstrated its remarkable promise in improving network performance in terms of interference management, network capacity and cell edge spectral efficiency (SE) [4]. In particular, downlink CoMP techniques enables multiple transmission points, hereafter called as base stations (BSs), to coordinate with each other for providing services to a particular user equipment (UE) in such a way to best serve the user demand. Joint transmission (JT), dynamic point selection (DPS) and coordinated scheduling/coordinated beamforming (CS/CB) are the three major downlink CoMP techniques outlined by 3GPP [4], [5]. In JT technique, multiple coordinating BSs transmit data simultaneously to a UE and thus improves the received signal quality as well as SE. In contrast, under DPS technique, although UE data is available to multiple coordinating BSs, only one of the BSs is selected for transmission. However, based on the wireless resource availability and channel state information, transmitting BS serving a specific UE can be switched among the coordinating BSs at the subframe level [4]. On the other hand, in CS/CB technique, UE scheduling/beamforming decisions are made through coordination among the cooperating BSs, while data for transmission to UE is only available at and transmitted from one BS. Selection of transmitting BS is chosen in a semi-static manner configured by higher-layer radio resource control signaling [4].

However, the benefit of improved SE from CoMP techniques might be offset by additional energy expenditure as SE and EE sometimes conflict with each other [6]. Owing to this context, several works comparing the energy requirement of cellular networks with various CoMP techniques to that with no-CoMP have been published [7] - [12]. For instance, EE of JT CoMP technique for single-tier hexagonal cellular network was investigated in [7], which found significant gains in throughput as well as energy savings especially for cell-edge users. A comparative analysis on the EE in terms of bits per joule of all the aforementioned three downlink CoMP techniques was presented in [8]. Based on the findings, the authors recommended JT and CB for future green cellular networks as they require less energy than that in DPS scheme. Another work

on the EE of JT technique with the constraint of guaranteed coverage under various network settings was presented in [9]. Furthermore, a comparison of energy requirements between JT and relaying techniques for homogeneous cellular networks published in [10] found that based on the network scenario, either of the techniques can be more energy efficient than the other. A clear preference for JT over relaying in terms of EE under dense deployment of BSs was also identified. On the other hand, authors in [11] investigated the EE feature for heterogeneous cellular networks with JT and found the optimum number of coordinating BSs. It was concluded that increasing the number of coordinating BSs above the optimum figure would decrease the network EE. Unlike the aforementioned works, authors in [12] thoroughly investigated the EE of CB technique specifically for cell-edge users and compared it with that of conventional multi-antenna techniques.

This paper proposes a novel CoMP technique for the downlink LTE-A cellular networks and investigates its EE in terms of bits per joule. Under the proposed CoMP technique, both DPS and JT techniques are applied together for further improving network SE. More specifically, for serving a specific UE, several BSs from the available are first chosen based on certain criteria and then these selected BSs simultaneously transmit to the UE. A two-tier heterogeneous network model consisting of high-power macrocells and low-power small cells is considered. Both random as well as deterministic patterns for spatial distribution of small cells in a macrocell are investigated. Furthermore, for maintaining a minimum distance between any two small cells, a Poisson distributed hard core point process (HCPP) is employed for modeling the location of small cells in all the spatial distribution scenarios. EE performance of the proposed CoMP technique under shadow fading environment is evaluated through extensive Monte-Carlo simulations, which is then compared with that of non-CoMP system with macrocell only, only JT and only DPS based cellular networks. Relations of EE performance metric with that of various network parameters, namely the number of coordinating BSs, small cell thinning radius and spatial distribution of small cells are thoroughly investigated and critically analyzed.

The rest of this paper is organized as follows: Section II explains the network model with the proposed CoMP technique and other key features. Simulation results and an in depth analysis is presented in Section III. The key findings are finally summed up in Section IV.

## II. NETWORK MODEL WITH THE PROPOSED CoMP TECHNIQUE

### A. Network Layout

We consider the downlink of a two-tier heterogeneous LTE-A cellular network having a mix of high-power macrocells and low-power small cells. Cells are assumed to have circular coverage with macrocell radius  $R_m$  and small cell radius  $R_s$ , where  $R_m > R_s$ . A section of the network with a single macrocell and several small cells are shown in Fig. 1. Three

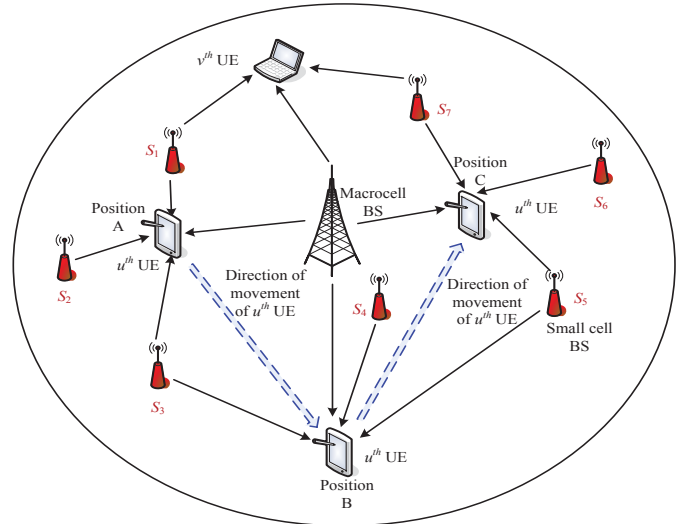


Fig. 1: A two-tier heterogeneous network model with the proposed CoMP technique.

different spatial distributions of small cells inside a macrocell are considered: random pattern, deterministic pattern and mixed pattern. In case of random pattern, as shown in Fig. 2(a), small cells are uniformly distributed throughout the macrocell coverage. In contrast, under the deterministic pattern shown in Fig. 2(b), small cells are placed on a circle of certain radius  $\Delta_s$  with macrocell BS at the center. On the other hand, in the third and the final case, named as mixed pattern, BSs are placed simultaneously on multiple pre-specified circles of radius  $\Delta_s$  surrounding the macrocell BS.

For all of these three cases, location of small cells (e.g., on a circle) are modeled using a Poisson distributed hard core point process (HCPP). First, a Poisson point process (PPP) is used to model the locations of small cells. Although this model closely resembles the real-life random BS locations and coverage areas, it does not put any kind of restriction on the minimum distance between any two BSs, i.e., two BSs can be very close to one another. However, in practice, BSs must have some geographic distance from neighboring BSs. For emulating such practical phenomena, we apply a particular thinning process on the PPP model such that no two small cell BSs can stay closer than a certain distance  $h$  resulting in a Matern II type HCPP distributed small cells.

### B. Proposed CoMP Technique

This paper proposes a new CoMP scheme for the downlink of LTE-A cellular networks by combining JT and DPS techniques. Under the proposed model, a UE is assumed to receive service always from the macrocell and on top of this, if the UE is under the coverage of other small cell(s), it can simultaneously receive data from one or multiple small cells as well. Therefore, the macrocell is always kept in active mode for guaranteeing the service to those UEs located outside the small cells' coverage.

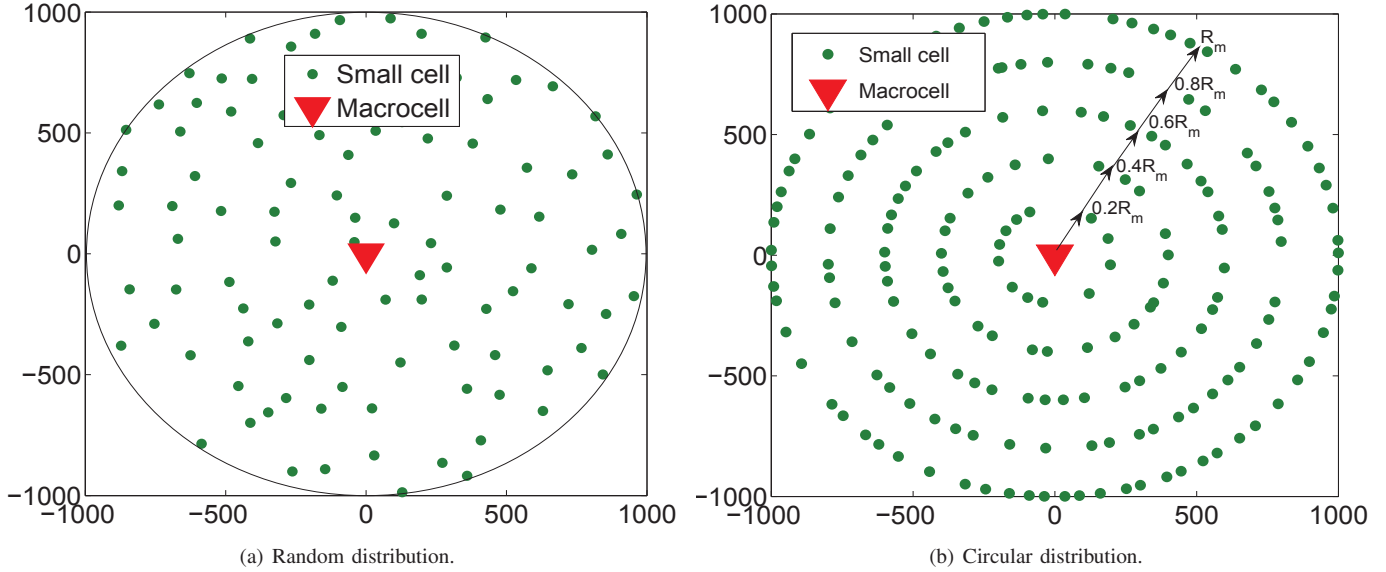


Fig. 2: Spatial distribution of small cells in a macrocell coverage area.

Therefore, when a UE is under the coverage of other small cells, i.e., the received signal-to-interference-plus-noise ratio (SINR) from corresponding BS is above a certain threshold, the UE ranks the available small cells in a descending order of received SINRs. Then the UE selects the top  $N_s$  small cells and requests them as well as the macrocell for jointly providing service in the downlink. The sorted list of available small cells is updated periodically as the received SINRs can vary due to the change in network environment, mobility of UEs, etc. The operation principle of the proposed CoMP technique is illustrated in Fig. 1. For instance, the  $u^{th}$  UE is served by the macrocell and three other small cells  $S_1 - S_3$  at position A. As the  $u^{th}$  UE moves from A to B, from the available BSs, a new sorted list of small cells (namely,  $S_3 - S_5$ ) based on the received SINR is selected for jointly serving the UE. Thus, both the the DPS and the JT transmission schemes are implemented together in the proposed CoMP technique. The small cells which does not have any UE to serve are switched into sleep mode for saving energy.

It is worth to be noted that deploying macrocells and small cells together for CoMP transmission systems may introduce some practical complexities, which is mainly due to the different hardware configurations, fading conditions, inter-tier interference, unbalanced uplink and downlink requirements, etc. Considerations of such implementation issues are beyond the scope of this paper and left as open issues for future research.

### C. Link Model

We consider a channel model with log-normally distributed shadow fading. Thus, the received power  $P_{i,i}^r$  at  $u^{th}$  UE located

at a distance of  $d_{i,u}$  from  $i^{th}$  BS can be given by

$$P_{i,u}^r = P_{i,u}^t d_{i,u}^{-\alpha} 10^{\zeta/10} \quad (1)$$

where  $P_{i,u}^t$  is the transmitted power at  $u^{th}$  UE from  $i^{th}$  BS,  $\zeta$  is a Gaussian random variable with mean zero and standard deviation  $\sigma$  dB, and  $\alpha$  is the path-loss exponent. Then the received SINR  $\gamma_{i,u}$  at at  $u^{th}$  UE from  $i^{th}$  BS can be given by

$$\gamma_{i,u} = \frac{P_{i,u}^r}{\mathcal{I}_{u,inter} + \mathcal{I}_{u,intra} + \mathcal{P}_N} \quad (2)$$

where,  $\mathcal{I}_{u,inter}$  is the inter-cell interference,  $\mathcal{I}_{u,intra}$  is the intra-cell interference,  $\mathcal{P}_N$  is the additive white Gaussian noise (AWGN) power given by  $\mathcal{P}_N = -174 + 10 \log_{10}(\Delta f)$  in dBm with  $\Delta f$  is the bandwidth in Hz.

On the other hand, in this paper, we adopt a "separate carriers" network model assuming different spectrum band for each cell, which is a common practice in industry [13], [14]. Thus, we can ignore all inter-cell interference. Furthermore, LTE-A system employs orthogonal frequency division multiple access (OFDMA), which results in zero intra-cell interference. Network analysis with the proposed CoMP technique considering inter-cell interference is left for future work.

### D. BSs Power Consumption Model

We consider that both macrocells and small cells can be operated in two different modes - active mode and sleep mode. However, in our proposed network, macrocells always remain in active mode, while a small cell can switch to sleep mode if there is no UE to serve. We adopt a linear power consumption model of BSs under which the total power consumption in a

TABLE I: BS power consumption model parameters [15]

BS Type	$N_{TRX}$	$P_{MAX}[W]$	$P_0[W]$	$\Delta P$	$P_S[W]$
Macro	1	20.0	130.0	4.7	75.0
Small	1	0.13	6.8	4	4.3

BS can be given by [15]

$$P_C = \begin{cases} N_{TRX}P_0 + P_{OUT}\Delta P, & \text{Active mode} \\ N_{TRX}P_{sleep}, & \text{Sleep mode} \end{cases} \quad (3)$$

where  $N_{TRX}$  is the number of transceivers per BS,  $P_{MAX}$  is the maximum transmit power of an active BS,  $0 \leq P_{OUT} \leq P_{MAX}$  is the actual transmit power,  $P_{sleep}$  is the sleep mode power consumption,  $P_0$  is the power consumption at zero output power (i.e., no UE to serve) and  $\Delta P$  is the slope of the load-dependent power consumption profile.

### E. Performance Metric

The total achievable network throughput can be calculated by Shanon's capacity formula as given below

$$R_{total} = \sum_{u=1}^U \sum_{i=1}^{N_{s,u}+1} \Delta f \log_2(1 + \gamma_{i,u}), \text{ bps} \quad (4)$$

where  $N_{s,u}$  is the number of transmitting small cells for serving  $u^{th}$  UE and  $U$  is the total number of UEs in the network.

On the other hand, if  $M_{active}$  and  $M_{sleep}$  are the total number of active and sleep mode BSs respectively, total power consumed by the network can be written as

$$P_{total} = \sum_{m=1}^{M_{active}} P_{m,active} + \sum_{n=1}^{M_{sleep}} P_{n,sleep}, \text{ Watt} \quad (5)$$

where  $P_{m,active}$  and  $P_{n,sleep}$  are the total power consumption in  $m^{th}$  active mode and  $n^{th}$  sleep mode BSs respectively as defined in (3).

In this paper, we evaluate the EE performance of the network with the proposed CoMP technique in terms of bits per joule, which is defined as the ratio of aggregate throughput  $R_{total}$  of the network to the total power consumed by the network  $P_{total}$ . Thus the EE metric denoted as  $\eta_{EE}$  can be written as

$$\eta_{EE} = \frac{R_{total}}{P_{total}}, \text{ bit/joule} \quad (6)$$

Then the normalized  $\eta_{EE}$  of the proposed network can be evaluated by taking the ratio of EE metric found in (6) to that of the traditional non-CoMP based cellular networks with macrocell only. This unit less normalized  $\eta_{EE}$  thus implies the EE improvement by the proposed CoMP technique over the conventional macrocell non-CoMP systems.

## III. RESULTS AND ANALYSIS

### A. Simulation Setup

Performance of the proposed downlink CoMP technique in terms of EE is evaluated through Monte-Carlo simulations. The

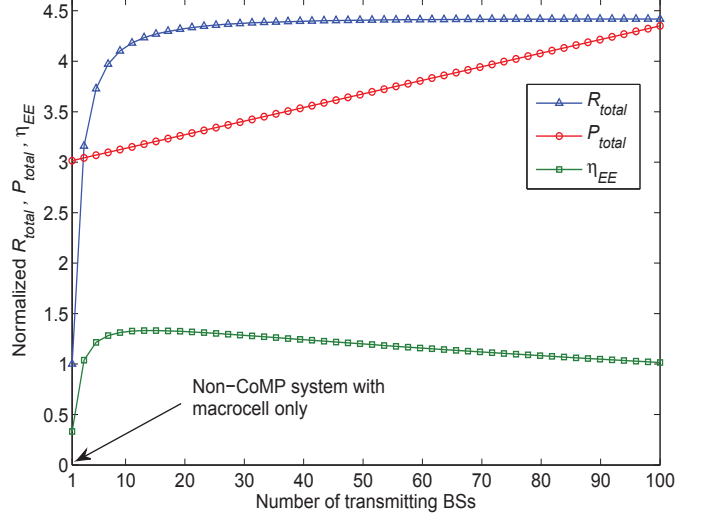


Fig. 3: Total throughput, energy consumption and EE metric with the number of jointly transmitting BSs for random spatial distribution of small cells.

results presented in this section are calculated by averaging over 10,000 independent simulations and normalized by the corresponding parameters of the non-CoMP based single-tier cellular network with macrocell only. Because of the adoption of "separate carriers" model, it is sufficient to consider a single macrocell with small cells distributed throughout its coverage area. Since intra-cell interference is zero in OFDMA based LTE-A systems, without losing the generality, we investigate the network performance considering a single UE in macrocell of interest assuming that the entire set of resource blocks (RBs) of the BSs is allocated to that UE.

On the other hand, BSs are assumed to have omnidirectional antennas (i.e.,  $N_{TRX} = 1$ ) with carrier frequency = 2 GHz, and channel bandwidth 5 MHz (i.e., 25 RBs) and 1.4 MHz (i.e., 6 RBs) are considered for macrocell and small cell respectively. Power consumption model parameters for both the macrocell and the small cell BSs are presented in Table I [15]. For the channel, a path-loss exponent  $\alpha = 3.574$  and shadow fading standard deviation 8 dB is used for the simulations [16]. Unless otherwise stated, a radius of  $R_m = 1000$  m is assumed for the macrocell, while the small cells are placed maintaining an HCCP thinning radius equal to 100 m.

### B. Results Analysis

Fig. 3 presents the variation of normalized throughput, energy consumption and the EE metric with the number of transmission points (TPs), i.e., BSs selected for jointly serving the UE. For the figure, small cells are considered randomly distributed following a uniform distribution within the macrocell coverage area. Number of serving BSs equal to one implies the case of conventional macrocell transmission only as the macrocell always transmits to the UE. As seen from the figure,

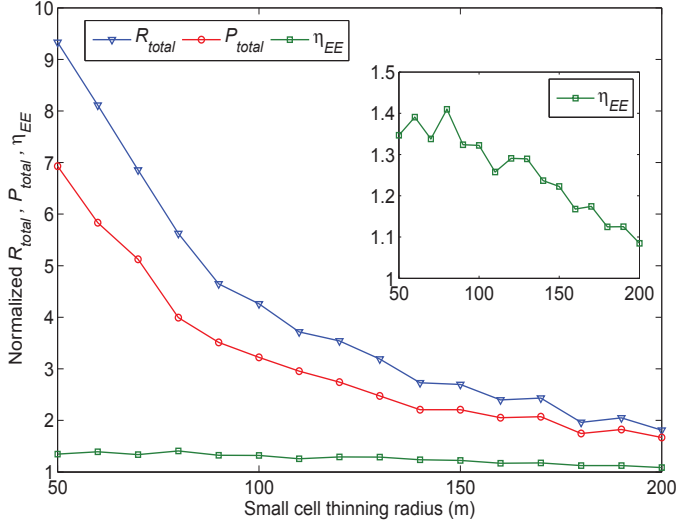


Fig. 4: Total throughput, energy consumption and EE metric with small cell thinning radius for random spatial distribution of small cells.

normalized throughput starts to increase rapidly for the smaller number of transmitting BSs. As the number of BSs increases, total throughput eventually reaches to a constant value. This is because, the BSs which are far away from the UE has negligible contribution to the throughput as the SINR becomes very low. On the other hand, as the number of transmitting BSs increases, number of active mode small cell BSs increases leading to linearly increasing total energy consumption by the network. The figure also includes the normalized EE metric  $\eta_{EE}$  which also increases with the increase of the number of transmitting BSs, reaches a peak value and then starts to fall beyond the point. Number of transmitting BSs corresponding to this peak  $\eta_{EE}$  indicates the optimal number of TPs to be selected that maximizes the number of bits transmitted per unit energy for the case of random spatial distribution of small cells. From the EE metric curve, it can readily be identified the optimal number as equal to 14.

Impact of small cell thinning radius on the normalized total throughput, energy consumption and EE metric of the proposed CoMP technique based cellular networks is demonstrated in Fig. 4. The network is simulated for the case of random spatial distribution of small cells and the number of BSs including the macrocell selected for transmission is considered equal to 14, which is the optimal number for such scenario as identified in Fig. 3. As the thinning radius increases, the density of small cells inside the macrocell decreases. Consequently, the small cells are going further away from the UE leading to reduced SINR resulting a lower throughput as evident from the figure. On the other hand, as the number of small cell continuously decreases with the increase of thinning radius, total energy consumption by the network decreases as well.

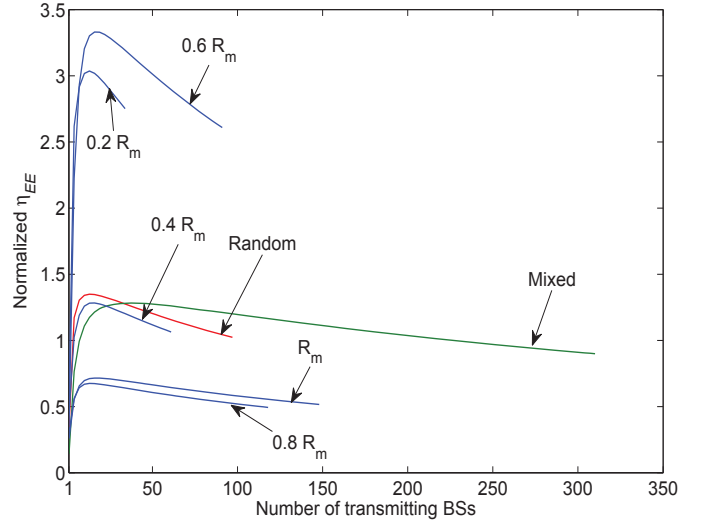


Fig. 5: Impact of spatial distribution of small cells on the EE of a cellular network with the proposed CoMP technique.

As these two curves (i.e., throughput and energy consumption) decrease in a similar fashion, normalized EE metric  $\eta_{EE}$  shows small changes including some minor fluctuations. However, the normalized  $\eta_{EE}$  curve still has a decreasing trend with the increasing small cell thinning radius as seen in the zoomed figure. For instance, as the small cell thinning radius is increased from 50m to 200m, normalized  $\eta_{EE}$  has decreased from 1.35 to 1.1. From the analysis of this figure, it can be identified that smaller thinning radius is preferred when distributing small cells in a macrocell from the view point of energy efficiency.

Dependency of EE on the spatial distribution of small cells inside a macrocell is illustrated in Fig. 5. Results for three different scenarios, namely, random distribution, circular pattern and a mixed scenario deploying several circular patterns together are shown. For the random case, small cells are once again uniformly distributed as in Fig. 3. For the circular pattern case, small cells are located at equal distances centering the macrocell BS. With the increase of the radius of this circle, number of small cells also increases. The figure includes the plots of  $\eta_{EE}$  where the small cells are placed on circles with radii  $\Delta_s = 0.2R_m : 0.2R_m : R_m$ . Finally in the mixed case, small cells are placed on all of these five circles simultaneously. Notably, all of the curves have a similar pattern reaching their peak values at their respective number of transmitting BSs. Interestingly, the best EE is found for the case when the small cells are distributed on a circle with radius equal to  $0.6R_m$ , while the worst is achieved for  $0.8R_m$ . On the other hand, EE of both the random distribution and the mixed cases lie around the the mid-range between the best and the worst cases.

Finally, a comparison of the EE performance of the proposed CoMP technique based cellular networks with that of only JT and only DPS based counterparts is presented in Fig. 6. The figure includes the results for the scenario of random spatial

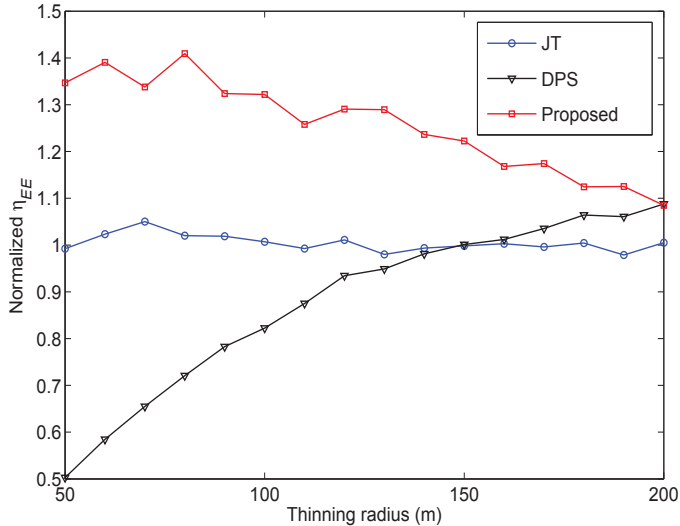


Fig. 6: EE comparison of JT, DPS and the proposed combined JT and DPS CoMP technique for random spatial distribution of small cells.

distribution of small cells and as in 4, the number of BSs selected for transmission is considered equal to 14. As seen, for the specified range of thinning radius, the proposed CoMP technique is the best in terms of EE with higher performance gap for smaller thinning radii. With the increase of the small cell thinning radius, normalized  $\eta_{EE}$  slowly decreases for the proposed CoMP technique, while remains almost same for only JT and increases for only DPS CoMP schemes, and thus the performance gap tends to diminish.

#### IV. CONCLUSIONS

This paper has proposed a novel CoMP technique for the downlink of two-tier heterogeneous LTE-A cellular networks and thoroughly investigated its EE performance. The new CoMP technique has been developed by combining the conventional DPS and JT CoMP schemes. EE performance of cellular networks with the proposed CoMP technique has been investigated through extensive simulations. Various spatial distribution of small cells including random locations, fixed patterns located on the circles centering the macrocell BS and a mixed scenario have been considered. For maintaining a minimum distance between any two small cell BSs, a Poisson distributed HCPP is also integrated for modeling their locations. It has been found that EE of the proposed CoMP system reaches its corresponding optimum value for a certain number of small cell BSs selected for transmission for serving an UE. Furthermore, a profound impact of spatial distribution of small cells as well as the small cell thinning radius on the EE performance of the proposed CoMP technique has also been clearly identified. Comparison of the proposed CoMP technique with that of only JT, only DPS and no-CoMP transmission techniques have also shown its superior EE performance for a wide range of network scenarios.

Our future works will include the analysis of EE as well as its trade-off with SE of the proposed CoMP technique for generalized multi-tier cellular networks with the consideration of inter-cell interference.

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