A Novel CoMP Transmission Mechanism for the Downlink of LTE-A Cellular Networks

[1]Ahnaf S. Ahmad, [2]Md. Jamiul Huque and [3]Md. Farhad Hossain
Department of Electrical and Electronic Engineering,
Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh.
Email: [1]ahnaf2194@gmail.com, [2]ronok.buet@gmail.com, [3]mfarhadhossain@eee.buet.ac.bd

***Abstract*—Introduced by long-term evolution-advanced (LTE-A) cellular systems, coordinated multi-point (CoMP) transmission has shown remarkable aptitude for improving network performance. This paper proposes a novel CoMP technique for the downlink of two-tier heterogeneous LTE-A cellular networks. Thorough investigation is carried out to evaluate its performance in terms of total throughput, energy efficiency and outage probability. The effect of interference is also taken in to consideration in this regard. The proposed technique combines both dynamic point selection (DPS) and joint transmission (JT) CoMP schemes. Under the proposed CoMP technique, multiple transmitting base stations (BSs) selected dynamically from available macrocells and small cells coordinate to jointly serve a user. Extensive simulations are carried out for evaluating the performance of cellular networks integrating the proposed CoMP technique and also compared with that of non-CoMP, only JT and only DPS based schemes.**

***Index Terms*—Performance Analysis; CoMP; Dynamic Point Selection; Joint Transmission; LTE-A.**

I. INTRODUCTION

In recent years, the widespread availability of internet access, diverse multimedia applications and introduction of new generation UE terminals have resulted in a massive growth of cellular network data traffic. Correspondingly, the ever-growing energy requirement to maintain such a demand has both economic and environmental impact. This has led to higher network operating cost and deterioration of global warming phenomenon [1]. Therefore, researchers are continuously looking for techniques to provide for such high traffic demand at lowest possible cost and environmental impact. As a result, system capacity as well as energy efficiency (EE) are prime performance metrics for planning and operation of modern day cellular networks.

However, coordinated muli-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 [2]. CoMP techniques have been proved to provide a phenomenal uplift in network performance in terms of interference management, network capacity and cell edge spectral efficiency (SE) [3]. Specifically, downlink CoMP techniques take advantage of multiple transmission points, termed as base stations (BSs) which coordinate with one another to provide best possible services to a particular user equipment (UE). Joint transmission (JT), dynamic point selection (DPS) and coordinated scheduling/coordinated beamforming (CS/CB) are the three major downlink CoMP techniques outlined by 3GPP [3], [4]. In JT technique, multiple coordinating BSs transmit data simultaneously to a UE. This improves both the received signal quality and SE. On the other hand, in DPS scheme, only one of the BSs is selected for transmission in spite of UE data being available to multiple coordinating BSs. However, transmitting BS serving a specific UE can be switched among the coordinating BSs at the subframe level based on the wireless resource availability and channel state information [3]. Finally, in CS/CB technique, while data for transmission to UE is only available at and transmitted from one BS, UE scheduling/beamforming decisions are made through coordination among the cooperating BSs. Selection of transmitting BS is chosen in a semi-static manner configured by higher-layer radio resource control signaling [3].

Owing to this context, several works have already analyzed CoMP concepts. Authors of [5] discussed CoMP in the context of heterogeneous implementation, where they examined the applications of cooperative relaying schemes in LTE-advanced systems. Moreover, in context of multi-cell interference a survey report is presented in [6] where authors correlated and compared CoMP with other techniques, namely static ICIC and dynamic ICIC. According to [7], a gain in the downlink cell-edge throughput as well as cell average throughput can be achieved in LTE-Advanced network with the CoMP transmission architecture. It refers to the possibility of coordinating the downlink transmission towards the same user adopting multiple BSs. Also, authors at [8] found significant rate gains and energy savings using JT-CoMP (compared to the single point transmission) especially for users in the cell-edge area.

However, the benefit of improved SE from CoMP techniques might be a matter of trading-off with additional energy expenditure [9]. Therefore, substantial effort has been put to improve EE. In [10], authors proposed a cell switch off scheme to enhance energy saving using CoMP transmission technique and showed the advantages in terms of both energy and capacity efficiency. Moreover, as presented in [11], EE increases with the number of users, which is due to multi-user diversity, and is more improved in techniques with larger number of users. According to them, JT and CB could be the feasible CoMP techniques to have more energy efficiency. In [12], authors concluded that setting some remote radio equipment (RRE) in sleep mode on the basis of traffic threshold consumes less

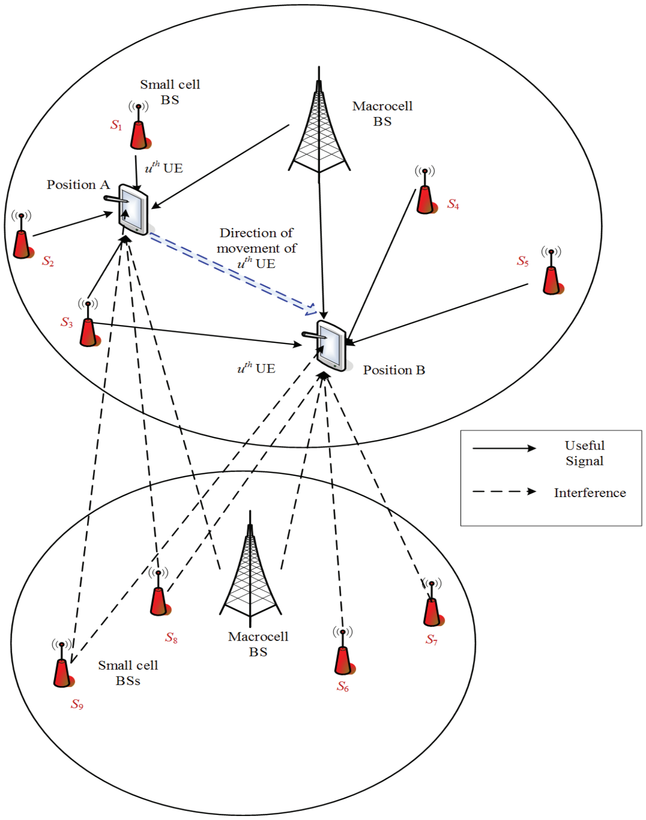

Fig. 1: A two-tier heterogeneous network model with the proposed CoMP technique.

energy. Besides, energy-efficient cell selection and resource allocation (ECR) have been discussed in [13]. They proposed to increase system energy efficiency by handovering UEs from light-loaded base station to nearby cells.

This paper proposes a novel CoMP technique for the downlink LTE-A cellular networks and investigates outage probability, traffic capacity and EE in terms of bits per joule. Our proposed CoMP technique combines both DPS and JT techniques with the intention of further improving network SE. To serve a specific UE, several BSs are first chosen based on their relative distance from the the UE and then these selected BSs simultaneously transmit to the UE. Gere, we consider a two-tier heterogeneous network model consisting of high-power macrocells and low-power small cells. 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. Network 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, system with only JT or DPS scheme. Relations of network throughput, outage and EE with that of various network parameters, like the number of coordinating BSs and small cell thinning radius 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*

The downlink of a two-tier heterogeneous LTE-A cellular network is considered consisting of 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 $R_m > R_s$. Such a segment of the network with a two macrocells and several small cells are shown in Fig. 1. Random pattern of spatial distributions of small cells inside a macrocell is considered. However, when interference is to be taken into account, we investigate the network performance under the coverage of a single macrocell while the neighboring macrocells and small cells inside them are assumed to be providing interference only.

Location of small cells are modeled using a Poisson distributed hard core point process (HCPP) [14]. 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, an UE is always served by the macrocell and 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. However, in the proposed model, all the cells are considered to be in active mode always, i.e., always consuming power regardless of the fact whether the UE in consideration gets service from them or not.

Therefore, when a UE is under the coverage of multiple small cells, i.e, if 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 their distance from the UE. Then the UE selects the nearest 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 based on the instantaneous position of the UE with respect to the BSs. 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. At this position, the UE also receives interference from two of the small cells located in the neighboring macrocell as shown in the Fig. 1. 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 distance is selected for jointly serving the UE. At the same time, the number of interfering cells has increased from two to five including four small cells and one macrocell. Here it is noteworthy that the nearest cells are not guaranteed to provide the best possible SINR due to the random nature of shadowing which is also considered in our simulation. Thus, both the the DPS and the JT transmission schemes are implemented together in the proposed CoMP technique. However, one of the principal assumptions in our model is, all the small cells are kept in active mode all the time. Although we consider a single UE in the simulation, all the existing BSs in the network are assumed to be serving different UEs all the time thus always consuming energy.

C. Link Model

We consider a channel model with log-normally distributed shadow fading. Thus, the received power $P^r_{i,i}$ at u^{th} UE located at a distance of $d_{i,u}$ from i^{th} BS can be given by

$$P^r_{i,u} = P^t_{i,u} d^{-\alpha}_{i,u} 10^{\zeta/10} \tag{1}$$

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

$$\gamma_{i,u} = \frac{P^r_{i,u}}{\mathcal{I}_{u,inter} + \mathcal{I}_{u,intra} + \mathcal{P}_N} \tag{2}$$

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 $\mathcal{P}_N = -174 + 10log_{10}(\Delta f)$ in dBm with Δf is the bandwidth in Hz.

In this paper, we have carried out the simulation both with and without considering interference. If we adopt a ”separate carriers” network model assuming different spectrum band for each cell, which is a common practice in industry [15], [16], 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. However, network analysis with the proposed CoMP technique considering inter-cell interference is also discussed in this paper.

D. BSs Power Consumption Model

In our proposed network, both macrocells and small cells always remain in active mode. We adopt a linear power consumption model of BSs under which the total active mode power consumption in a BS can be given as [17]

TABLE I: BS power consumption model parameters [17]

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

$$P_C = N_{TRX} P_0 + P_{OUT} \triangle_p, \text{Watt} \tag{3}$$

where N_{TRX} is the number of transceivers per BS, P_{MAX} is the maximum transmitted power of an active BS, $0 \leq P_{OUT} \leq P_{MAX}$ is the actual transmitted power, P_0 is the power consumption at zero output power (i.e., no UE to serve) and Δ_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

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

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} is the total number of active mode BSs, total power consumed by the network can be written as

$$P_{total} = \sum_{m=1}^{M_{active}} P_{m,active}, \text{Watt} \tag{5}$$

where $P_{m,active}$ is the total power consumption in m^{th} active mode as defined in (3). However, as we consider that all the small cells are in active mode all the while, we can safely infer that the total power power consumption is the sum of all existing small cells' active mode power.

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 η_{EE} can be written as

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

Then the normalized η_{EE} of the proposed network can be evaluated by taking the ratio of EE metric found in (6) to that of the traditional no-CoMP based cellular networks with macrocell only. This unit less normalized η_{EE} thus implies the EE improvement by the proposed CoMP technique over the conventional macrocell non-CoMP systems.

Another important parameter to evaluate the performance of a system is the outage probability. Let, γ_{th} is the required minimum (i.e., threshold) SINR for a UE for its effective communication. Then the outage probability of u^{th} UE from i^{th} BS can be given by

$$P_{i,u}^{out} = Pr\{\gamma_{i,u} \leq \gamma_{th}\} \quad (7)$$

In our study, we evaluate our proposed technique in terms of outage probability against traditional no-CoMP based network and also with taking only JT and only DPS CoMP technique.

III. RESULTS AND ANALYSIS

A. Simulation Setup

Performance of the proposed downlink CoMP technique in terms of throughput, EE and outage is evaluated through Monte-Carlo simulations. The 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. We take in to consideration a single macrocell with small cells distributed throughout its coverage area where the neighboring macrocells provide interference. As we consider that all the small cells are active always, 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. That is, the entire resource block is occupied by either the UE in consideration or by some other UEs. On the other hand, BSs are assumed to have omni-directional 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 = 3.574 and shadow fading standard deviation 8 dB is used for the simulations [16]. For the case without considering interference, a radius of Rm = 1000 m is assumed for the macrocell, while considering interference a 19 cell cluster consisting of cells each having a macrocell radius of Rm = 1000 m is assumed. In both cases, the small cells are placed maintaining an HCCP thinning radius equal to 100 m.

B. Result Analysis

Fig. 2 presents the variation of normalized throughput and the EE metric with the number of transmission points (TPs), i.e., BSs selected for jointly serving the UE for both with and without interference. For the figure, small cells are considered randomly distributed 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. Also, when number of serving BSs is equal to two, the curve indicates that only DPS CoMP technique is carried out. That is, only one small cell which is indeed nearest to the UE transmits along with the macrocell itself. Finally, when number of transmitting BSs reaches it's terminal value, the curves indicate the condition as if only JT CoMP technique is in action.

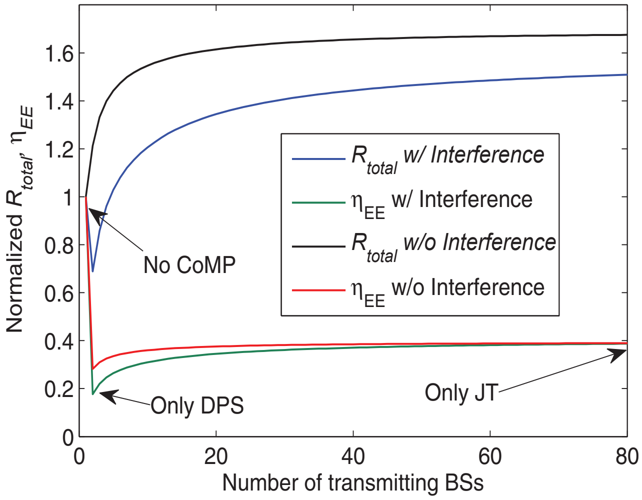

Fig. 2: Total throughput and EE metric with the number of jointly transmitting BSs for random spatial distribution of small cells.

As seen from Fig. 2, normalized throughput starts to increase rapidly for the smaller number of transmitting BSs when interference is not taken into account. As the number of BSs increases, total throughput eventually reaches to a near constant value. This is because, the BSs which are far away from the UE have negligible contribution to the throughput as the SINR becomes very low. On the other hand, as the number of transmitting BSs increases, total energy consumption doesn't change because all the transmitting BSs are considered to be in active mode always. The figure also includes the normalized EE metric η_{EE} which is very low when only a small number of BSs transmit but increases with the increase of the number of transmitting BSs, reaches a peak value and then remains almost constant. Number of transmitting BSs corresponding to this peak η_{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 40. However, it is to be noted that, normalized EE metric takes a sudden fall when number of serving BSs is equal to two i.e. only DPS is in action. This happens because when only a single small cell transmits along with the macrocell, all remaining small cells in the coverage area are active too. The energy consumption due to this is far greater than the corresponding throughput. So, normalized EE metric is very low in this case. However, as the energy consumption doesn't change with the rising number of serving BSs, increased throughput eventually forces normalized EE metric to rise.

On the other hand, taking inter-cell interference into account, the variation of performance parameters against varying number of transmitting BSs for random distribution of small cells is also presented in Fig. 2. As mentioned previously, a nineteen cell

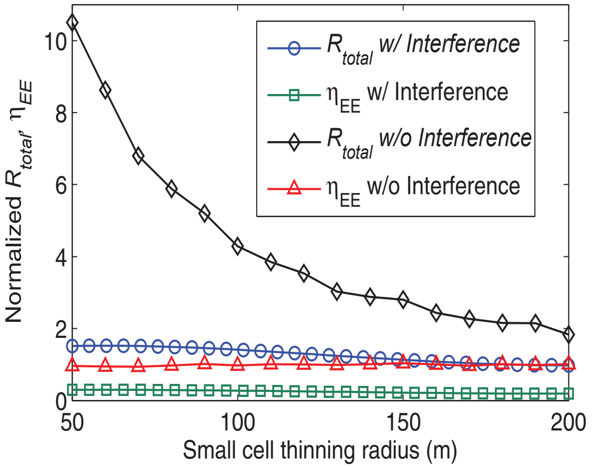

Fig. 3: Total throughput and EE metric with small cell thinning radius for random spatial distribution of small cells.

cluster is assumed to fully realize the effect of interference. As seen from Fig. 2, the effect of interference is much prominent when a few number of small cells are selected for transmission. This is due to the fact that when a few number of small cells transmit, all the remaining BSs along with BSs from neighboring macrocells provide interference. This results in a dip in received SINR which eventually leads to low available throughput. However, as the number of transmitting BSs increases, throughput gradually increases as the received SINR from transmitting BSs overcomes the interference power. The normalized EE metric curve shows the same pattern as the case without interference due to the reasons explained beforehand.

Impact of small cell thinning radius on the normalized total throughput and EE metric of the proposed CoMP technique based cellular networks is demonstrated in Fig. 3. 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 40, which is the optimal number for such scenario as identified in Fig. 2. 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. However, power consumption in the system is a linear function of the number of active small cells in the system as discussed in Section II-D. As the thinning radius increases, fewer small cells are available which leads to a gradual decrease in energy consumption. Therefore, normalized EE metric η_{EE} shows small changes including some minor fluctuations. However, 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 achievable throughput. On the other hand, the effect of small cell thinning radius while considering inter-cell interference is also shown in Fig. 3. However, normalized throughput is rather low in this case compared to the previous one due to the effect of interference. Unlike in the case of without interference, the normalized EE metric clearly shows a downward trend due to decreasing throughput.

Finally, the outage probability for different techniques without and with interference is shown in Fig. 4 and Fig. 5 respectively. In the case without interference, Fig. 4 clearly shows that the CoMP techniques perform a lot better than

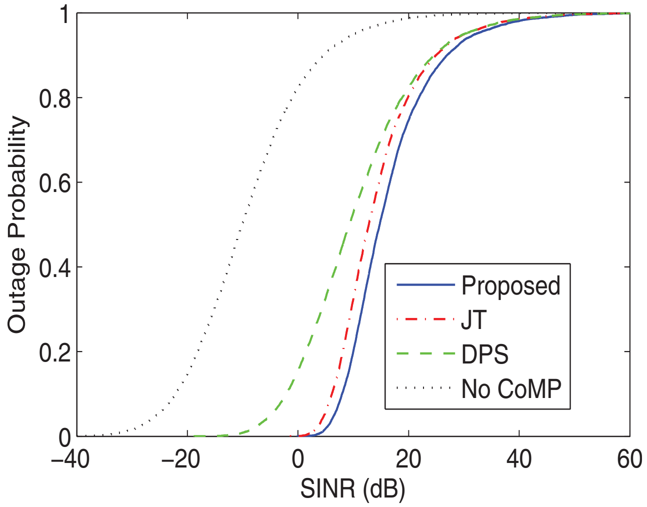

Fig. 4: Comparison in terms of outage probability for different techniques without interference.

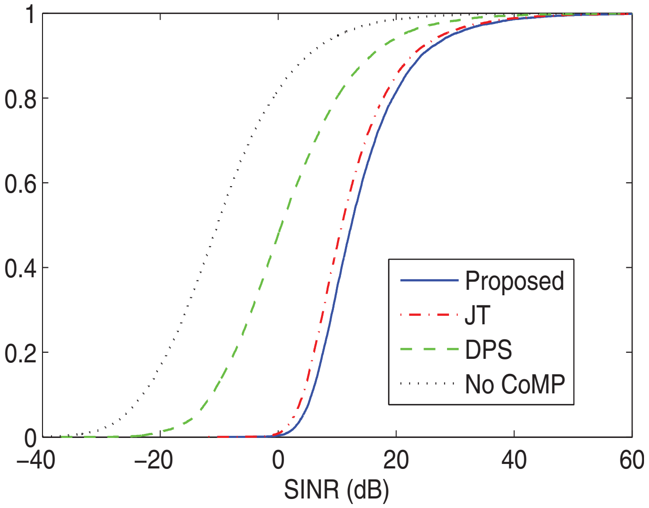

Fig. 5: Comparison in terms of outage probability for different techniques considering interference.

the traditional macrocell based scheme in terms of outage. However, our proposed model shows superior performance over both DPS and JT CoMP techniques. The same observation can also be made for the case considering interference as evident from Fig. 5.

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 performance in terms of throughput, EE performance and outage probability. Simulation results indicate that both total achievable throughput and outage probability improve with varying network parameters. Comparison of the proposed CoMP technique with that of only JT, only DPS and no-CoMP transmission techniques have also shown its superior outage performance for a wide range of network scenarios. However, keeping all the small cells in active mode always i.e., the worst case scenario in terms of energy consumption results in the reduction of EE. With the effect of interference already discussed in this paper, 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 and proposing an improved model to ensure superior EE performance.

REFERENCES

[1] M. F. Hossain, K. S. Munasinghe and A. Jamalipour, “Distributed Inter-BS Cooperation Aided Energy Efficient Load Balancing for Cellular Networks,” *IEEE Transactions on Wireless Communications*, vol. 12, no. 11, pp. 5929-5939, Nov 2013.

[2] I. F. Akyildiz, D. M. G. Estevez and E. C. Reyes, “The Evolution to 4G Cellular Systems: LTE-Advanced,” *Physical Communication*, vol. 3, no. 4, pp. 217-244, Dec 2010.

[3] J. Lee, Y. Kim, H. Lee, B. Ng, D. Mazzarese, J. Li, W. Xiao and Y. Zhou, “Coordinated Multipoint Transmission and Reception in LTE-Advanced Systems,” *IEEE Communications Magazine*, vol. 50, no. 11, pp. 44-50, Nov 2012.

[4] D. Lee, H. Seo, B. Clerckx, E. Hardouin, D. Mazzarese, S. Nagata and K. Sayana, “Coordinated Multipoint Transmission and Reception in LTE-Advanced: Deployment Scenarios and Operational Challenges,” *IEEE Communications Magazine*, vol. 50, no. 2, pp. 148-155, Feb 2012.

[5] Q. Li, R. Q. Hu, Y. Qian, G. Wu, “Cooperative communications for wireless networks: techniques and applications in LTE-advanced systems,” *IEEE Wireless Communications*, vol. 19, no. 2, Apr. 2012.

[6] E. Pateromichelakis, M. Shariat, A. ul Quddus, R. Tafazolli, “On the Evolution of Multi-Cell Scheduling in 3GPP LTE / LTE-A,” *IEEE Communications Surveys & Tutorials*, vol. 15, no. 2, pp. 701-717, Second Quarter 2013.

[7] Q. Wang, D. Jiang, G. Liu, Z. Yan, “Coordinated Multiple Points Transmission for LTE-Advanced Systems,” *5th International Conference on Wireless Communications, Networking and Mobile Computing, WiCom ’09*, pp. 1-4, 24-26 Sep. 2009.

[8] C. Khirallah, D. Vukobratovic, J. Thompson, “On energy efficiency of joint transmission coordinated multi-point in LTE-advanced,” *International ITG Workshop on Smart Antennas (WSA)*, pp. 54-61, 7-8 Mar. 2012.

[9] Y. Chen, S. Zhang, S. Xu, and G. Y. Li, “Fundamental Trade-offs on Green Wireless Networks,” *IEEE Communications Magazine*, vol. 49, no. 6, pp. 30-37, June 2011.

[10] G. Cili, H. Yanikomeroglu, F. R. Yu, “Cell switch off technique combined with coordinated multi-point (CoMP) transmission for energy efficiency in beyond-LTE cellular networks,” *IEEE International Conference on Communications*, pp. 5931-5935, 10-15 Jun. 2012.

[11] K. M. S. Huq, S. Mumtaz, J. Rodriguez, Rui L. Aguiar, “Comparison of energy-efficiency in bits per joule on different downlink CoMP techniques,” *IEEE International Conference on Communications*, pp. 5716-5720, 10-15 Jun. 2012.

[12] K. M. S. Huq, S. Mumtaz, M. Alam, A. Radwan, J. Rodriguez, “Energy efficient CoMP transmission in LTE-Advanced,” *IEEE Globecom Workshops*, pp. 401-404, 3-7 Dec. 2012.

[13] J. H. Chu, K. T. Feng, T. S. Chang, “Energy-efficient cell selection and resource allocation in LTE-A heterogeneous networks,” *IEEE 25th Annual International Symposium on Personal, Indoor, and Mobile Radio Communication*, pp. 976-980, 2-5 Sep. 2014.

[14] S. M. Hasan, M. A. H. Shiblu, M. F. Hossain, “On the Downlink SINR and Outage Probability of Stochastic Geometry Based LTE Cellular Networks with Multi-Class Services,” *Proc. of IEEE International Conference on Computer and Information Technology (ICCIT)*, pp. 1-5, Dec. 2015.

[15] L. Duan, J. Huang, and B. Shou, “Economics of Femtocell Service Provision,” *IEEE Transactions on Mobile Computing*, vol. 12, no. 11, pp. 2261-2273, 2013.

[16] J. D. Hobby and H. Claussen, “Deployment Options for Femtocells and their Impact on Existing Macrocellular Networks,” *Bell Labs Technical Journal*, vol. 13, no. 4, pp. 145-160, 2009.

[17] G. Auer, V. Giannini, C. Desset, I. Godor, P. Skillermark, M. Olsson, M. A. Imran, D. Sabella, M. J. Gonzalez, O. Blume and A. Fehske, “How Much Energy is Needed to Run a Wireless Network?,” *IEEE Wireless Communications*, vol. 18, no. 5, pp. 40-49, Oct 2011.