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Analysis on Energy Efficient Traffic Load Balancing in Downlink LTE-Advanced Heterogeneous Network

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***Abstract*—In this paper, a comprehensive analysis of energy efficiency for traffic load balancing using cell range expansion (CRE) for Pico cells is presented. The study focused on evaluating the energy efficiency for traffic load balance of Heterogeneous Network (HetNet) deployment scenario. Energy efficiency was modeled as ratio of total throughput to power consumption, thus power consumption is evaluated using base station power consumption parameters. Throughput is modeled based on the Signal Interference and Noise Ratio (SINR) link adaption, considering spatial distribution of User Equipment (UE). Simulations were carried out using 3rd Generation partnership (3GPP) Long Term evolution (LTE) system level simulator. The result obtained have shown that, for some traffic situations, the energy efficiency improves with balanced traffic load which further provided more insight for successful deployment of green heterogeneous cellular network.**

Keywords*—Heterogeneous Networkt; Pico Cell Range Expansion; Energy Efficiency; Traffic Load Balance

I. INTRODUCTION

The number of mobile subscribers is greatly increasing over the years. Currently there are over 7 billion mobile cellular telephone subscribers and over 3 billion active mobile broadband subscribers in the world [1]. The ITU-R report anticipated that the mobile data traffic will increase tremendously in all countries and areas in the world. Attractive mobile broadband services and improved device capabilities drive the strong increase in unprecedented traffic volumes and consumer data rate [2]. From Sample cases the mobile data traffic revenues are not commensurate to the actual traffic growth. For traffic growth of 350%, the total data revenues increased only by 30% [3]**.** The mobile network operators spend about 25% of the total network operation cost for electric energy which is largely generated from fossil fuel [4]. Since Traffic grows faster than revenue, networks must become more efficient**.**

The LTE-Advanced system with advanced technologies was meant to cost effectively address the increasing demand for quality of service (QoS), high data rates, and coverage extension to mobile users. These advanced technologies include; carrier aggregation (CA), Advanced MIMO techniques, coordinated multipoint transmission/reception (COMP) and Support for multi-tier deployment also known as Heterogeneous Network (HetNet) [5]. A network with a composition of MeNB and low-power nodes (femto, pico, micro and relay nodes), mixed access modes, and backhaul is referred to as HetNet [6]. Intelligent HetNet deployment and planning strategies is one of ways to improve the energy efficiency in a mobile network [7]**.** Using high density deployment of low power small base stations compared to low density deployment of high power macro base stations, has proven to decrease the power consumption. The fact being that a base station hereafter referred to as eNodeB (eNB), closer to mobile users lowers the required transmit power due to advantageous path loss conditions [8]**.** Network deployment based on smaller cells such as Micro, Pico or even Femto cells is a possible solution to reduce total power consumption of a cellular network [9]**.** Heterogeneous networks (HetNets) using Long Term Evolution (LTE)-Advanced system in 3GPP, achieve an overlay low power eNB onto high power macro eNB coverage using spectrum reuse of one. HetNets are being increasingly deployed by operators with macro-pico deployment as the most preferred deployment strategy [10]. In a typical macro-pico deployment scenario, Pico eNB (PeNB) with smaller transmission power and size compared to Macro eNB (MeNB) are deployed within the coverage area of a MeNB to increase capacity. Another benefit of deploying PeNB is to reduce coverage holes, where radio signal strength from MeNB is low that mobile stations, referred to as User Equipment (UEs) are not served by MeNB [10].

However, HetNet deployment brings about new challenges; due to diverse transmit power levels of different eNBs in HetNet [11]**.** Most UEs prefer to associate with the highest power eNB, when the conventional Reference Signal Received Power (RSRP)-based association scheme is employed [6]. This shifts the handover boundary between MeNB and PeNB closer to PeNB as depicted in Figure 1.

This result in uneven distribution of traffic load among different eNBs and in turn underutilization of the resource at low power PeNBs [11]. The 3GPP as part of it standardization effort proposed the Biased Reference Signal Received Power (BRSRP) based user association, to proactively offload users to smaller cells using an association bias [12]. BRSRP-based association also known as Pico Cell Range Expansion (PCRE) is a potential technique to solve the problem of traffic imbalance [11]. In such a technique, an arbitrary fixed bias is added to the received signal power from low-power small cell PeNBs that helps offloading more users from MeNBs to PeNBs. The value of the bias can be configured individually per cell Thus, setting bias greater than 0 for the PeNB and bias of 0 for the macro MeNB will results to PCRE [12]. This will therefore shift the handover boundary to the MeNB as depicted in Figure 1.

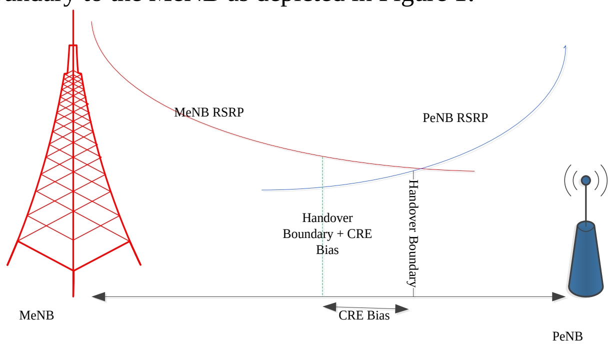

Figure 1. BRSRP based Association Scheme.

PCRE bias value does not virtually enlarge the transmission power from PeNBs, but makes User Equipment (UE) do handover earlier to the PeNBs since they have a positive PCRE bias value [13]. The coverage area is not affected by load imbalance in the uplink because the UE possesses equal transmit power [6]. PCRE provides significant improvement for UEs in the uplink as a result of reduce path loss since the link distance are reduced [14]. However, in the downlink transmission, pico cell-edge UEs are exposed to severe interference from MeNB for two reason: first the cell-edge UEs are furthest away from the serving PeNB. Secondly, this UEs are much closer to the interfering MeNB which consequently reduce their rate. Hence PCRE for pico cells lead to uplink downlink traffic imbalance [14]. This reduce the overall throughput consequently reducing the downlink transmission energy efficiency of the network.

In this paper, a comprehensive analysis of the impact PCRE on transmission energy efficiency and traffic load balance in LTE-Advanced HetNet is presented. The objective of this paper is to evaluate the transmission energy efficiency, average UE throughput, and pico UE proportions of different PCRE bias values. In order to demonstrate the impact of PCRE association in LTE-Advanced HetNet.

II. RELATED LITERATURE

The work in [15] Investigates the impact of deploying different numbers of small nodes on reducing area power consumption, or alternatively, on enhancing the throughput power consumption of access networks. In [16] a power consumption model for LTE and LTE-Advanced macro cell and femto cell eNB was proposed and a suitable energy efficiency measure was developed, to compare the design of LTE to energy efficient LTE-Advanced Networks. The work in [7] presented a theoretical modeling of energy efficiency in Heterogeneous networks (HetNets). Simulation result shows that the pico cell strongly impacts the energy efficiency of the HetNet as compared to micro cell. More specifically the work demonstrated that certain ratios of Micro cells and Pico cells per Macro BS will result in sub-optimal of Area Energy Efficiency (AEE). In [17] a heuristic algorithm for eNB selection was proposed. The algorithm maximizes energy efficiency by reducing the energy consumption in LTE HetNet without compromising the QoS of UEs, defined as minimum data rate. In [18] a path loss-based eNB selection procedure to realize CRE was proposed. The algorithm associates UEs to eNBs with the lowest path loss.

Other works focus on biased receive power based user associations as PCRE technique. In [12] it was indicated that PCRE bias values have to be carefully set to achieve optimal load-aware performance. The global optimal solutions for dynamically selecting optimized bias was proposed in [19] and [12], and it was observed that there is a gap between an optimized but static PCRE and the globally optimal solution. Static PCRE has the advantage of offering much lower complexity and overhead (both computational and messaging) than optimizing the PCRE for each network realization. The effects of PCRE on energy efficiency was investigated in [20]. This paper intends to investigate how PCRE affect energy efficient and traffic load balancing in configuration 1 of the 3GPP HetNet deployment scenario.

III. SYSTEM MODELS, SCENARIO DESCRIPTION AND SIMULATION ASSUMPTIONS

A. System Models

The system performance evaluation of PCRE technique was carried out using a multi-cell system level simulation according to LTE specifications as defined in [21] and [22]. The investigated scenario is HetNet configuration 1. Table I gives the summary and definitions of the RSRP and PCRE association scheme and other variables which is considered in this paper.

The conventional RSRP cell association was modeled as:

$$CellID_{RSRP} = \max\{RSRP_m, RSRP_p\} \tag{1}$$

Whereas the PCRE was modelled as

$$CellID_{PCRE} = \max\{RSRP_m, RSRP_p + B_n\} \tag{2}$$

For this work, single antenna receivers and transmitters are assumed, and therefore, only large-scale parameters are considered in the channel model according to [22].

$$P_{RX} - P_{TX} = L_P + F_S + G_A + L_{misc} \tag{3}$$

The downlink Signal to Interference and Noise Ratio between any serving eNB and any UE is given in [7] as:

$$SINR\,(uid,d) = P_{TX} + G_A - N - I - F_S(d) - L_P(d) - PLN, \tag{4}$$

Where: N and I are the noise and the inter-cell-interference (ICI) power from all the interfering eNBs at the UE location respectively. PLN is the wall penetration loss for signals received by indoor UE. Finally $PL\ (d)$ and (d) are the path loss and shadow loss in dB respectively measured at different UE positions. The Shanon approximation formula for the spectral efficiency was modeled according to [23] as

$$S(bps/Hz) = BW_{eff}.log2\left(1+\frac{SINR}{SINR_{eff}}\right) \quad (5)$$

TABLE I. SUMMARY OF VARIABLES

Variables	Definitions
CellID	Cell where UE receive maximum RSRP
$RSRP_m$,$RSRP_p$	RSRP from MeNB and PeNB respectively
B_n	CRE bias value for PeNB
$SINR_{eff}$	SINR efficiency
$SINR_{threshold}$	SINR value corresponding to the 26 MCSs level.
P_{RX}	UE received power
P_{TX}	eNB transmit power
L_P	Path loss
F_S	Fading due to shadowing
G_A	Directional antenna gain
L_{misc}	Any miscellaneous loss such as feeder cable loss
BW_{eff}	Bandwidth efficiency

Link adaptation was used to map SINR to corresponding Transmission Block Size (TBS). Link adaptation requires the selection of a proper Modulation and Coding Scheme (MCS) according to the channel quality which is usually indicated by the SINR reported by each UE. Following the LTE specification in [21], three modulation levels of Quadrature Phase Shift Keying (QPSK), 16-QAM and 64-QAM are supported. Together with turbo coding there are 26 MCSs levels, this imply that there are 26 Channel Quality Indicators (CQI). The SINR to the effective SINR ($SINR_e$) mapping was modeled as:

$$SINR_e(uid,d) = \max\ \{SINR(uid,d)\,,\ SINR_{threshold}\} \quad (6)$$

$SINR(uid,d)$ Is the SINR as a result of the UE's instantaneous channel conditions as in equation (4). The mapping of SINR to TBS of the 26 MCSs levels, assuming a Block Error Rate (BLER) target of 10% according to [24] was modelled as:

$$TBS(uid,d) = TBS(SINR_e(uid,d)) \quad (7)$$

Throughput (R) for a UE *i* is given in [23] as**:**

$$R(i) = \frac{TBS(i)\,x NRB}{TTI}(1 - BLER(i)) \quad (8)$$

Where $TBS(i)$ is The physical transmission block information capacity (in bits) for the each UE CQI state I, and $BLER(i)$ is the average BLER, TTI is the transmission time interval and NRB is the number of resource block allocated to UE i. In this paper round robin resource scheduler is considered which is modeled as:

$$NRB(uid,d) = \frac{NRB}{NumUEperCell} \quad (9)$$

Where: *NRB(uid,d)* is the number of resource block allocated to a user at distance d from an eNB.

Assuming static power consumption irrespective of traffic load situations, the base station power consumption is defined as in [7] as:

$$Pc_i = Nsec*Nant\ (Ai*P_{TX} + Bi) \quad (10)$$

Where *Nsec* and *Nant* denote the eNBs's number of sectors and the number of antennas per sector, respectively. *Pci* is the average total power of base station(s) in a cell and P_{TX} is the power fed to the antenna as defined in equation (3). The coefficient *Ai* accounts for the part of the power consumption that is proportional to the transmitted power, which include Radio Frequency (RF) amplifier power and feeder losses. While *Bi* denotes the power that is consumed independent of the average transmit power which include signal processing and site cooling [7]. The value of the parameters are specified in table II.

The energy efficiency is defined as the ratio of the total throughput (*R*) within a cell and the total power consumption of the cell (*PCi*), which is expressed as [7]:

$$EE_{Ci} = \frac{overall\ data\ rate}{total\ power\ consumed} = \frac{RCi}{PCi} \quad (11)$$

Where: RCi is the overall throughput in bits/s within a cell, and PCi is the total power consumption of the cell in watts and EE_{Ci} is the transmission energy efficiency to all UEs in bits/joule within the cell.

B. Scenario Description and Simulation Assumptions

Based on the 3GPP LTE system level simulations toolbox define in [25], a system of 7 wraparound sectored MeNB (21 cells) with 4 PeNB per sector is considered in this work. The PeNBs are randomly drop within a MeNB area with minimum inter-site distance constrains. Each sector has a directional antennas at 120 degrees apart one for each sector, while the PeNB has Omni-directional antenna. Users are uniformly distributed throughout the coverage area following the HetNet configuration 1 topology. Mobility is represented by users having different locations in each drop. Other related system level simulation parameters are specified in Table II.

The performance evaluation was carried out in a 3GPP LTE system level simulator. The following metrics was used for performance evaluation:

- PeNB UEs (PUE) proportion: Number of UEs connected to PeNBs.
- Average cell energy efficiency: energy efficiency averaged over all simulated cells from all simulation drops.
- Cell average PUE and MeNB UE (MUE) throughput: average UE throughput will indicate how well the traffic load is balanced between PeNBs and MeNB [25].

IV. RESULTS AND DISCUSSION

In this section, the overall simulation results for the conventional RSRP cell association scheme and PCRE association schemes with different bias considered in this work is presented. The simulation was carried out for different number of UEs in the HetNet configuration 1. The proportions of UEs connected to the PeNBs increased with the increase in PCRE bias due to the offloading of more UEs from MeNB to PeNBs as a result of the effect of PCRE bias. The proportion of UEs connected to PeNB for PCRE with bias of 3dB, 6dB, 9dB, 12dB and 16dB were found to be about 7% 9% 15% 20% and 26% higher than the conventional RSRP cell association scheme respectively.

TABLE II. SYSTEM LEVEL SIMULATION PARAMETERS

Parameter		Setting/Description
Cell layout		7 Hexagonal MeNBs; 3 sectors; reuse 1
MeNBs radius		500m
Bandwidth and carrier frequency		10MHz at 2000 MHz
Hotspot radius		4
Hotspot radius		40m
Minimum distance between	MeNBs and PeNBs	75m
	Among PeNBs	40m
	MeNBs and UE	35m
	PeNBs and UEs	10m
Transmission power	MeNBs	46 dBm
	PeNBs	30 dBm
Path-loss	MeNBs	128.1 +37.6$\log_{10}$ (r [km]) [21]
	PeNBs	140.7 +36.7$\log_{10}$ (r [Km]) [21]
Number of UEs per sector		10,20,...,100
UE distribution		Uniform distribution [21]
Packet scheduler		Round Robin
$BW_{eff}, SINR_{eff}$		0.75 , 1.25 [22]
Power consumption parameters		Macro:*Ai* = 21.45; *Bi* = 354.44, Pico: *Ai* = 5.5; *Bi*=38[6]

For the individual bias values, the proportion of PeNB UEs increase up to 30UEs in the system, but allowing up to 40 UEs into the system, however, caused a decrease in the connection ratio. It subsequently stabilized when more UEs were allowed into the system beyond 40 UEs. Therefore, it can be deduced that the best offloading gain for all the bias values is achieved when 30UEs are allowed in the system. Nevertheless, the connection ratio does not show significant difference with the rest of number of UEs for all the bias values. This is consistent with what is reported in [26].

The cumulative distribution functions (CDF) of the SINR of PCRE cell association schemes with 4 PeNBs and 100 UEs per sector lie above the SINR CDF of conventional RSRP as the reference cell association scheme. The worst affected UE by interference in all the cell association schemes are the cell edge (worst 5%) UEs [26].

Essentially, any offloading due to increase in PeNB cell range will result in SINR performance degradation of the offloaded UEs [27]. This is due to the interference effect suffered by pico cell-edge UEs from the high transmission power of MeNBs. Consequently, the SINR CDF for the cell edge UEs of the PCRE with 16dB, was found to be the worse followed by 12dB, 9dB, 6dB than the SINR CDF of the conventional RSRP respectively. PCRE with 3dB did not show significant difference with the conventional RSRP. This shows that without effective interference mitigation the cell edge UEs will be in an outage, with large PCRE bias values. The pico UE connection ratio, CDF of the SINR and CDF of spectral efficiency (SE) is presented in Fig. 2, Fig. 3 and Fig. 4 respectively.

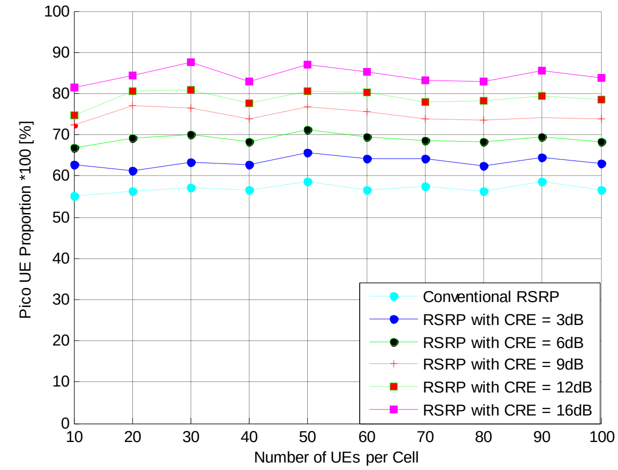

Figure 2. PeNB UE Proportion

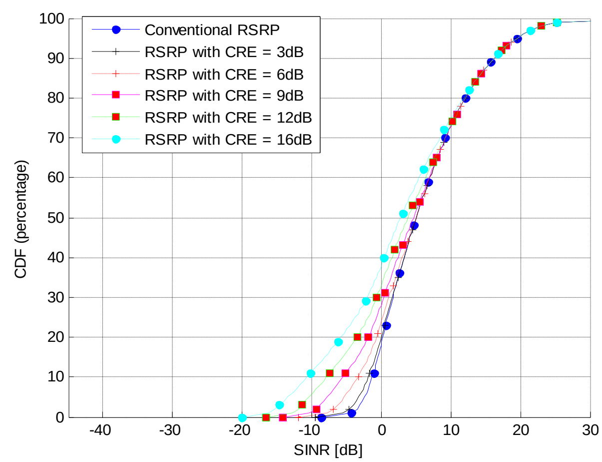

Figure 3. The CDF of SINR with Different PCRE Bias

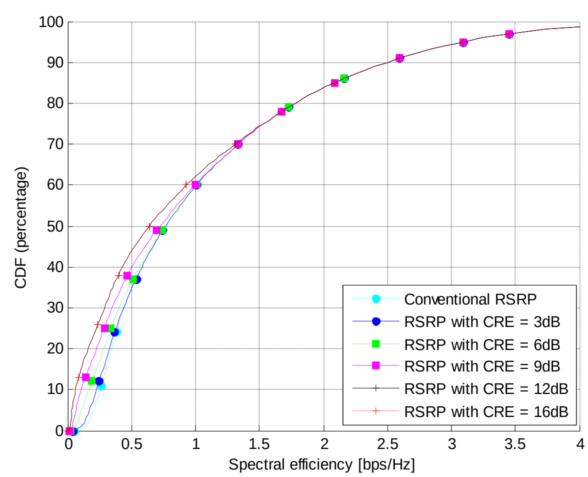

Figure 4. The CDF of SE with Different PCRE Bias

The spectral efficiency (SE) is the measure of utilization of bandwidth measured in bps/Hz, the corresponding performance for the conventional RSRP and PCRE is depicted in Fig. 4. The average (50% CDF) SE was not found to differ between the conventional RSRP and the RSRP with 3dB, 6dB and 9dB. But that of PCRE with 12dB and 16dB lie slightly above the conventional RSRP for less than 70% CDF after which it was not found to differ. The SE of the cell edge (worst 5%) UEs for the conventional RSRP and all the PCRE bias were poor due to the poor load balancing in the case of the conventional RSRP and poor SINR in the PCRE scheme.

RSRP with bias of 3dB exhibited a more balanced average UE throughput performance for low traffic load (10UE per cell). For low traffic load, the difference between the average throughput performance of the PeNB UEs and MeNB UEs is 10.8Mbps, 1.1Mbps, 1.6Mbps, 8.4Mbps, 10.3Mbps and 15.2Mbps for conventional RSRP, PCRE with 3dB, 6dB, 9dB, 12dB and 16dB respectively. Hence, PCRE with 3dB has the lowest difference in the average UE throughput between the MeNB UEs and PeNB UEs.

PCRE with bias of 6dB exhibited a more balanced average UE throughput performance for medium traffic load (50UE per cell). Fig. 5 and Fig. 6 shows the average UE throughput for low and medium traffic load respectively.

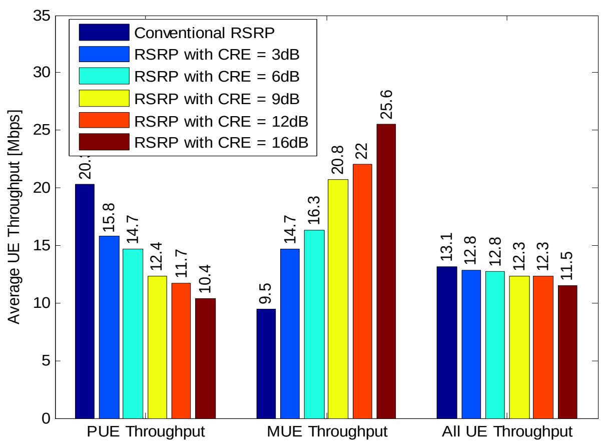

Figure 5. Average UE Throughput for Low Traffic Load

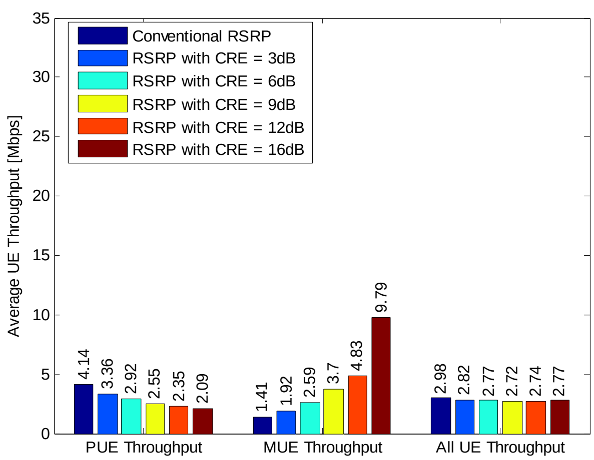

Figure 6. Average UE Throughput for Medium Traffic Load

For medium traffic load, the difference between the average throughput performance of the PeNB UEs and MeNB UEs is 2.73Mbps, 1.44Mbps, 0.33Mbps, 1.15Mbps, 2.4Mbps and 7.7Mbps for conventional RSRP, PCRE with 3dB, 6dB, 9dB, 12dB and 16dB respectively. Hence, PCRE with 6dB has the lowest difference in the average UE throughput between the MeNB UEs and PeNB UEs.

PCRE with bias of 9dB exhibited a more balanced average UE throughput performance for high traffic load (10UE per cell). For high traffic load, the difference between the average throughput performance of the PeNB UEs and MeNB UEs is 1.494Mbps, 1.001Mbps, 0.42Mbps, 0.13Mbps, 0.83Mbps and 1.81Mbps for conventional RSRP, PCRE with 3dB, 6dB, 9dB, 12dB and 16dB respectively. Hence, PCRE with 9dB has the lowest difference in the average UE throughput between the MeNB UEs and PeNB UEs as depicted in Fig. 7.

For all the traffic load considered the average PUE throughput decrease with increase in bias. This can be attributed to the fact that PCRE essentially offloads UE from MeNB to PeNB, the higher the PCRE bias the more the offloading gain. Therefore, the higher PCRE bias resulted to overcrowding the PeNB thereby lowering the average throughput of the PUEs due the round robin scheduler employed. The round robin resource allocation makes UEs to share the limited resource blocks in the pico cell equally. Also as the PCRE bias increase pico cell-egde UEs increase, such UEs are greatly impacted by interference from MeNB which consequently reduce their rate. Conversely, the average MUEs throughput increase with increase in bias. This can be attributed to the fact that, as UEs are offloaded to PeNBs from MeNB, fewer UEs are left in the MeNB to share the available resources and such UEs are not affected by interference. Therefore, such UEs achieve high data rate which is similar with what is reported in [27] and [28].

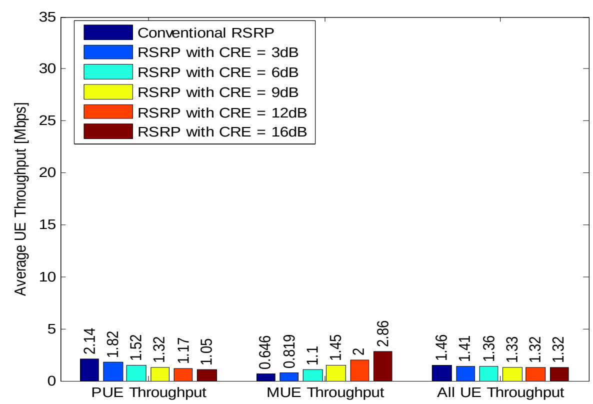

Figure 7. Average UE Throughput for High Traffic Load

The PCRE with 16dB bias achieve the worst average UE throughput (All UE throughput) and traffic load balance for all the traffic load considered. This can be attributed to poor SINR performance with 16dB and redundancy introduced to the MeNB due to limited UEs allowed in the MeNB. It can also be observed that the conventional RSRP achieved the best total UE throughput. This is because the conventional RSRP has the best SINR performance. However, the conventional RSRP achieve a poor traffic load balance. This is due to low offloading of UEs from PeNB to MeNB.

Despite the poor performance of the conventional RSRP in terms of traffic load balance, it was found to perform better in terms of energy efficiency. The conventional RSRP achieved the best energy efficiency for all traffic load simulated as depicted in Fig. 8. PCRE with 16dB achieved the worst energy efficiency due to poor SINR performance which lowers the total achievable throughput.

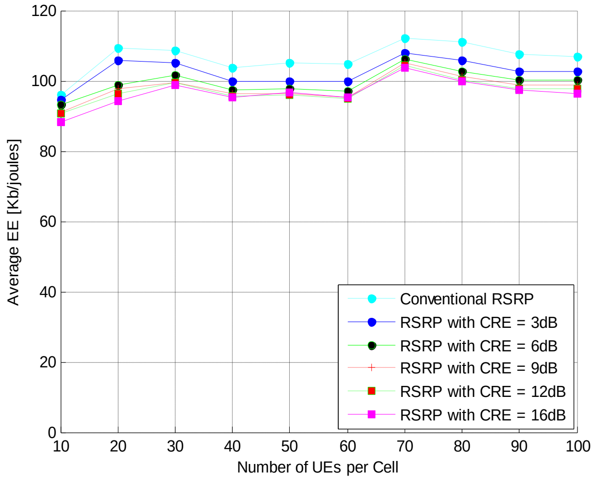

Figure 7. Average Energy Efficiency

V. CONCLUSION

HetNet deployment have the potential to improve capacity as well as energy efficiency. However poor cell association and poor HetNet deployment limit the potential of HetNet in improving energy efficiency and traffic load balance. Therefore, in this work, a comprehensive analysis on the effect of RSRP and Pico Cell Range Expansion (CRE) association scheme on energy efficiency and traffic load balance is presented. The modelling of the energy efficiency was based on base station power consumption and data rate. Thus the power consumption is evaluated using power consumption parameters and the data rate was modelled based on link adaptation considering spatial distribution of UEs. From simulation result it was found that, while RSRP achieves the best performance, PCRE reduce energy efficiency and overall average UE throughput. However for low medium and high traffic load, PCRE with bias 3dB, 6dB and 9dB achieves the best traffic load balance respectively. RSRP with bias of 16dB and conventional RSRP achieved poor traffic load balance. Therefore, PCRE with bias of 3dB to 9dB can achieve a tradeoff between traffic load balance and energy efficiency. Further work should look at achieving a tradeoff between traffic load balance and energy efficiency by jointly optimizing the two metrics.

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