Energy-Efficient Bias-Based User Association for Heterogeneous Networks in LTE-Advanced

Ayuba K. Danburam, Mohammed A. Gadam, Aliyu D. Usman and Suleiman M. Sani

Abstract Heterogeneous network (HetNet) deployment is a promising technique for improving energy efficiency in 4G and beyond wireless cellular systems. The major challenge of enhancing energy efficiency in HetNet is a poor cell selection when the conventional reference signal received power (RSRP) or biased RSRP (BRSRP) cell selection algorithm is employed. These cell selection techniques limit the potential of HetNet in improving transmission energy efficiency. The proposed energy-efficient bias setting strategy is an adaptive BRSRP cell selection algorithm. It uses energy efficiency as cell load metric for adaptive picocell range extension (CRE). The algorithm efficiently estimates the varying energy efficiency in each cell, then, based on the optimality gap of the energy efficiency, it adopts an optimized bias value per cell. Simulations using LTE system level simulator shows the proposed adaptive bias setting improves energy efficiency, average UE throughput and system capacity by 6.7, 9.7 and 6.9%, respectively when compared with BRSRP with a fixed bias of 6 dB. Although the proposed adaptive bias exhibits low offloading gain from PeNB to MeNB as against BRSRP, the system load balance has improved when compared with RSRP.

Keywords Heterogeneous network · Picocell range expansion · Cell selection · Energy efficiency · Traffic load balance

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1 Introduction

The demand for mobile broadband services and improved device capabilities drives the strong increase in the unprecedented traffic volumes and consumer data rate [1]. Deploying more macro base stations (BS) hereinafter referred to as Macro evolved NodeB (MeNB) onto an existing homogeneous network is limited by poor cell splitting gain due to high co-channel interference [2]. More so, the high cost of site acquisition and operational cost due to high energy consumption associated with MeNB deployment make it difficult to achieve desired revenue and quality of service. Therefore, with homogeneous deployment, the mobile data traffic revenues are not commensurate with the actual traffic growth. The mobile network operators spend about 25% of the total network operation cost on electric energy, which is largely generated from fossil fuel [3]. Therefore, the challenge is providing quality service while operating within acceptable cost of operation to the expanding mobile networks. To cope with this challenge, Heterogeneous Network (HetNet) deployment strategy was proposed and standardized by the 3rd Generation Partnership Program (3GPP) [4]. HetNet is realized by overlaying low power nodes (LPNs) onto high power macro area through spectrum reuse of one. The LPNs deployed in HetNet includes Pico eNodeB (PeNB), femtocell and relay nodes. HetNets are being increasingly deployed by operators, and PeNB is most preferred because of ease of planning and deployment [5]. Apart from improving capacity, another benefit of deploying PeNBs is to reduce coverage holes. Especially where radio signal strength from MeNB is low that user equipment (UE) is not served by MeNB [6]. More also, network deployment based on PeNB is a potential solution for reducing total power consumption of a cellular network [7]. The fact being that a base station referred to as eNodeB (eNB), closer to mobile users, lowers the required transmit power due to advantageous lower path loss [8].

However, HetNet deployment brings about new challenges due to the diverse transmit power levels of MeNB and PeNB in HetNet. Most UEs prefer to associate with the MeNBs, with the conventional reference signal received power (RSRP)-based user association scheme. This results in uneven distribution of traffic load and in turn underutilization of the resource in PeNBs [9]. In order to solve the problem of traffic imbalance, 3GPP as part of its standardization effort proposed the biased reference signal received power (BRSRP) user association also known as cell range expansion (CRE). This is aimed to proactively offload users to PeNBs by utilizing an association bias [10]. However, CRE with fixed bias lacks information on traffic load conditions in the cell due to the dynamic UE distribution as well as varying environmental conditions in the system [11]. This shortcoming results in a wrong bias setting, consequently, poor traffic load balance, reduced throughput, and hence reduced energy efficiency in the system. Therefore, bias for CRE needs to be dynamically set to adapt to traffic load for improved system performance [6].

In this chapter, an energy-efficient adaptive bias setting for optimal system performance is proposed. The proposed technique uses energy efficiency threshold estimated per macrocell area coverage, to represent cell load condition in order to set

PeNB bias value per cell. On one hand, the estimated energy efficiency per macro area represents the load condition in the cell and reduces the complexity associated with UE distribution. On the other hand, configuring bias values per cell reduces high signaling overhead and UE frequent handover associated with setting bias value per UE. More so, the bias value is dynamically set, if and only if a defined network energy efficiency threshold is reached in order to avoid frequent handover. The bias value is dynamically set to avoid poor bias setting due to varying load conditions and UE service demand.

Therefore, the main contributions of this chapter are as follows;

1. It proposed an adaptive bias cell association which uses energy efficiency as cell load metric and considers spatial distribution of UEs.
2. It developed a dynamic bias configuration strategy which enhances energy efficiency and traffic load balance with reduced network complexity and signaling overhead.

This chapter is organized as follows: Section 2 present related literature, Sect. 3 introduces cell association and its procedures and Sect. 4 presents the system model. Description of the proposed algorithm is presented in Sect. 5. Section 6 deals with the scenario description and the simulation assumptions, Sect. 7 presents results and discussion while Sect. 8 provides the conclusion of the chapter.

2 Related Literature

The fixed CRE bias value method implemented by authors in [11] is not practical due to the fact that networks need to adapt to the variations in environmental conditions. Hence, the adaptive bias proposed and studied by the authors in [11–16] was meant to address the issues of dynamics in environmental conditions. Proposed also by authors in [12, 15] was an adaptive cell range control in HetNet utilizing the cell edge UE capacity. This scheme assumed cell load metric to be represented by the number of pieces of UE as resource block utilization ratio (RBUR) acquired through the network. Near-optimal cell edge UE throughput gain of over 6 dB static bias setting was achieved by this scheme. Furthermore, since cell load estimation is acquired from the network side, this makes the scheme simple, devoid of feedback delays and errors. However, since traffic load varies with user mobility and the scheme is lacking criteria for deciding the cell load threshold, then number of pieces of UE employed by the authors cannot efficiently represent cell load condition.

The work in [13] presented a distributed Q-learning-based CRE in HetNet to improve both cell edge and average UE throughput, and outage reduction was employed as performance metric. The ratio of resource blocks to the UE distribution was also considered as cell load metric. The input to the algorithm is based on the previous experience of distributed pieces of UE that learn their optimal bias values. The algorithm achieves maximized network throughput since pieces of UE learn its bias values from past experience. However, due to the long convergence time associated with the Q-learning, it is therefore not suitable for real systems.

Further, parameter optimization for adaptive control CRE in HetNet based on SINR was studied by the authors in [14]. The scheme utilizes the ratio of the number of pieces of UE connected to PeNBs and MeNBs as cell load metric. The scheme input centralization was achieved due to the SINR feedback from UE. The ability of the algorithm to solve the trade-off between cell edge UE throughput and the average UE throughput makes it simple and with a near-optimal performance. However, since traffic load depends on resource block and SINR, the feedback from each UE also brought about delay in the system; therefore, the number of pieces of UE cannot efficiently estimate the cell's load condition.

The authors in [15] presented a simple cell association method for HetNets based on expected minimum average UE throughput. A combined metric comprising of MeNB index and resource index to maximize the UE throughput was employed as cell load metric. The decentralization of the inputs in the algorithm has therefore removed the need for coordination among MeNBs. It was evident that faster convergence was achieved by the algorithm, and further improved performance was also recorded with enhanced interference and inter-coordination (eICIC). The algorithm is robust in canceling the effect of interference because the eICIC has the ability to adapt according to the variation of UE distribution. However, large overheads due to feedbacks were observed in the algorithm which leads to frequent handover problems with multiple pieces of UE. It is a known fact that frequent handover leads to scheduling outage.

The authors in [16] proposed PeNB CRE-based cell association algorithm employing adaptive CRE bias in HetNet. The algorithm utilized the measurement in the uplink interference to adjust PeNB coverage areas dynamically. For the PeNB that suffers high interference, small CRE bias values are acquired to shrink their coverage areas. On the other hand, PeNBs subjected to less interference has their coverage areas extended to provide services for those areas previously covered by the loaded neighboring cells. To increase the uplink transmission rates, the algorithm makes cell selection decision based on the uplink interference. However, this may not necessarily provide the best downlink rates because the PeNB UEs in the range extended are exposed to severe interference from MeNB in the downlink, consequently, reducing their downlink data rates. Therefore, MeNB that gives the maximum uplink rates can be different from the one for the downlink.

The authors in [17] proposed a distributed, priority and non-biased-based channel access and load-aware association technique with interference mitigation in their most recent work. Their work proposed combined priority access based on maximum channel gain for high priority UEs and hybrid channel gain and access-based cell association for low priority UEs for rate maximization and load balancing. The work achieved a good traffic load balance and the best offloading gain from MeNB to PeNB when compared with RSRP and PeNB CRE with the fixed bias of 6 dB, respectively. Lower UE throughput was achieved despite employing interference mitigation because the resource blocks available in the PeNB were not able to compensate for the severe interference suffered by PeNB cell edge UEs. This ultimately affects the overall system performance and thereby reducing the energy efficiency of the network.

In the most recent work of authors in [18], the effect of RSRP cell selection algorithm and BRSRP with the different bias on energy efficiency and traffic load balance of downlink in LTE-Advanced HetNet was investigated and verified through simulation. The modeling of power consumption of base station was based on base station power consumption parameters, where power consumption was assumed to be constant irrespective of traffic [19]. The data rate was modeled based on link adaption considering spatial distribution of UEs. From simulation result, RSRP performed better in terms of total throughput and overall energy efficiency. However, RSRP achieved poor traffic load balance due to poor offloading gain from MeNB to PeNB. BRSRP with a bias of 16 dB achieved the worst performance due to severe interference. BRSRP with a bias between 3 dB and 9 dB achieved a trade-off between traffic load balance and system performance. Therefore, adaptive bias setting has the potential to improve system performance and traffic load balance.

3 Theoretical Background

Cell selection is the process in which pieces of UE attach themselves to the serving cell for communication based on certain criteria [11]. The cell selection criteria are determined by utilizing quality, coverage and load-based cell selection [16]. The quality-based cell selection is initiated when the UE has better channel quality with a candidate eNB than its serving eNB. And the coverage-based cell selection occurs when UE has measured better RSRP with a candidate eNB than it serving eNB. While in load-based cell selection, the congested eNB needs to handover some users to a neighboring eNB to balance the traffic load [16].

3.1 RSRP Cell Selection

The RSRP cell selection is a coverage-based cell selection, where UE connects to eNB that has the highest RSRP. For a HetNet, let RSRP from eNB n be denoted by P_n in dB and defined according to [6] as follows:

$$\mathrm{RSRP} = \arg\ \max_n\{P_n\} \tag{1}$$

The method in Eq. (1) results in the underutilization of the resource at low powered eNB(s) having lower transmit power, and it also tends to overload the high power eNB(s) having higher transmit power thereby reducing system performance [9]. This is due to the fact that data rate varies linearly with resource block. Hence, load balancing is very critical in achieving high data rates which is the key performance metric [17].

3.2 Biased RSRP (BRSRP)-Based Cell Selection

To tackle the traffic load balancing problem, the BRSRP-based association also known as cell range extension (CRE) is considered [10]. In such a scheme, an arbitrary bias is added to the RSRP from PeNBs which offloads users from MeNBs to PeNBs [18, 20]. CRE connects UEs to PeNB(s) rather than MeNB(s) by adding a bias value called the “PCRE bias value,” to the signal level received from PeNBs transmission power [18]. Hence, with CRE, PeNBs seem to have greater reference signal strength than usual. Let RSRP from PeNB n and the CRE bias value for the PeNB be denoted by P_n [dB] and B_n [dB], respectively. Then, the UE selects the serving eNB that connects with the UE by the following equation according to [2].

$$\mathrm{BRSRP} = \arg\ \max_n\{P_n + B_n\} \tag{2}$$

For the purpose of pico CRE, B_n is selected to be a positive value so that the handover boundary is shifted closer to the MeNB as in [6] depicted in Fig. 1.

CRE bias value does not increase the transmission power from the PeNBs but makes UEs do handovers earlier to the PeNBs since they have a positive CRE bias value [6]. The coverage area is not affected by load imbalance in the uplink because the UE holds equal transmit power [16]. CRE provides significant improvement for UEs in the uplink as a result of reduced path loss since the link distance are

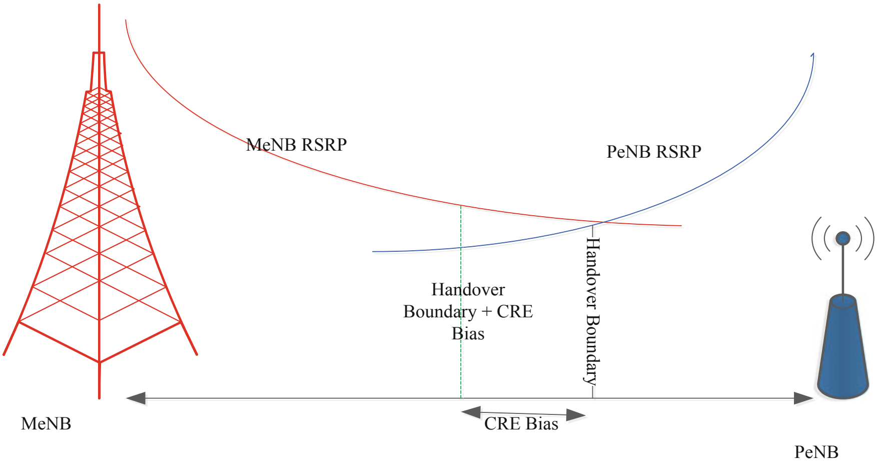

Fig. 1 Biased receive signal power based association scheme

reduced. However, in the downlink transmission, picocell edge UEs are exposed to severe interference from MeNB for two reasons: First, the picocell edge UEs are furthest away from the serving PeNB. Secondly, this UEs are much closer to the interfering macrocells. These consequently reduce the throughput of the picocell edge UEs as data rate varies logarithmically with SINR. CRE for picocells leads to uplink-downlink traffic imbalance [16].

Therefore, with RSRP, heavily loaded MeNB provides lower data rates despite holding higher SINR, and with BRSRP, the available resource in PeNB cannot compensate for the lower SINR. Hence, adaptive bias setting that considers the dynamic distribution of UEs will achieve a better system performance.

4 System Model

The default cell selection criteria in HetNet are the conventional RSRP for 3GPP release 8/9 and BRSRP for 3GPP release 10/11 [17]. However, both RSRP and BRSRP cell selection criteria suffer the same problem of poor energy efficiency and traffic imbalance even with the best network configuration. Therefore, an energy-efficient cell selection criterion is proposed based on adaptive bias setting. RSRP for MeNB and PeNB was modeled according to [5] as follows:

$$\mathrm{RSRP}_m = \mathrm{PTX}_m - \mathrm{PL}(m) - \mathrm{SF}(m) + \mathrm{GA}(m) - L_{\mathrm{misc}} \tag{3}$$

$$\mathrm{RSRP}_p = \mathrm{PTX}_p - \mathrm{PL}(p) - \mathrm{SF}(p) + \mathrm{GA}(p) - L_{\mathrm{misc}} \tag{4}$$

where RSRP_m and RSRP_p are RSRP from MeNB and PeNB, respectively, PTX_m and PTX_m are transmit power of MeNB and PeNB, respectively in dB, $\mathrm{PL}(m)$ and $\mathrm{PL}(p)$ are path loss of UE from MeNB and PeNB, respectively, $\mathrm{SF}(m)$ and $\mathrm{SF}(p)$ are shadows fading for MeNB and PeNB, respectively, $\mathrm{GA}(m)$ and $\mathrm{GA}(p)$ are antenna gain of MeNB and PeNB, respectively, and L_{misc} is any miscellaneous losses. The conventional RSRP and BRSRP cell association was modeled as follows:

$$\mathrm{RSRP} = \max\left\{\mathrm{RSRP}_m, \mathrm{RSRP}_p\right\} \tag{5}$$

The BRSRP was modeled as follows:

$$\mathrm{BRSRP} = \max\left\{\mathrm{RSRP}_m, \mathrm{RSRP}_p + B_n\right\} \tag{6}$$

whereas the proposed energy-efficient bias setting (EEBS) was modeled as follows:

$$\mathrm{EEBS} = \max\left\{\mathrm{RSRP}_m, \mathrm{RSRP}_p + \beta_n(\mathrm{EE}_H)\right\} \tag{7}$$

where B_n is the fixed CRE bias value for PeNB in dB, β_n is the variable CRE bias value which varies in the range of 0–16 dB and EE_H is highest downlink energy efficiency for each network realization. Therefore, UE to eNB association decision will vary for different association schemes as follows:

i. RSRP: The new users will likely associate to MeNB due to higher transmitted power.
ii. BRSRP: For reasonably large values of bias which is static, the new user will be forced to select the PeNB.
iii. EEBS: Depending on the estimated downlink energy efficiency, a dynamic bias value is set and the new users can choose to associate between MeNB and PeNB.

Other benchmark models for measuring system performance such as throughput, energy efficiency and load balance are also presented in this section. In this section data rate and throughput are used interchangeably. The detailed scenario description is presented in Sect. 6.

4.1 Capacity Model

For this chapter, round-robin resource allocation was used, where it was assumed that users within a cell share the available resource block equally so that they can attain higher data rate [21]. Therefore, the number of resource block allocated to a user at distance d from an eNB per transmission time interval was modeled according to [22]:

$$\mathrm{NRB}(\mathrm{uid}, d) = \frac{\mathrm{NRB}/\mathrm{TTI}}{\mathrm{NumUEpercell}} \tag{8}$$

where NRB is the number of resource block per cell, NumUEperCell is the number of UE per cell; TTI is the transmission time interval. Therefore, from Eq. (8), the number of resource block for a pico UE and a macro UE was modeled respectively as follows:

$$\mathrm{NRB}_{\mathrm{Pico}}(h, k) = \frac{\mathrm{NRB}}{q} \tag{9}$$

$$\mathrm{NRB}_{\mathrm{macro}}(h) = \frac{\mathrm{NRB}}{p} \tag{10}$$

where h has values from 1 to the number of MeNB and k has values from 1 to the number of PeNB per macrocell, $\mathrm{NRB}_{\mathrm{Pico}}(h, k)$ is the resource block available to a user connected to a picocell k in a macrocell h, $\mathrm{NRB}_{\mathrm{macro}}(h)$ is the resource block available to a user connected to a macrocell h, while q and p are the number of users connected to picocell k and macrocell h, respectively. The data rate for a

UE is calculated based on the UE distance d from the eNB, the average signal to interference and noise ratio (SINR) at the UE is defined according to [22, 23] as;

$$\mathrm{SINR}(\mathrm{uid}, d) = \mathrm{PTX} + \mathrm{GA} - N - I - \mathrm{SF}(d) - \mathrm{PL}(d) - L_{\mathrm{misc}} \quad (11)$$

where PTX is the eNB transmission power (per cell sector); GTx *and* GRx are the eNB and UE antenna gains, respectively. N and I are the noise and the inter-cell interference (ICI) power from all the interfering eNBs at the UE location respectively. L_{misc} is any miscellaneous loss e.g. the wall penetration loss for signals received by indoor UE. Finally, PL(d) and SF(d) are the path loss and shadow loss in dB, respectively, measured at different UE positions.

In LTE, the Media Access Control (MAC) layer allocate the physical Transmission Block Size (TBS) which depends on the Modulation and Coding Scheme (MCS) selected by the MAC layer scheduler. This is based on the Channel Quality Indicator (CQI) reported by the UE after every Transmission Time interval (TTI) of 1 ms [22]. Link adaptation requires the selection of a proper MCS according to the channel quality which is usually indicated by the SINR reported by each UE [24]. Following the LTE specification in [25], three modulation levels of QPSK 16-QAM and 64-QAM are supported. Together with turbo coding, there are 26 MCSs, this implies that there are 26 CQI. The SINR to TBS mapping for these MCSs, assuming a block error rate (BLER) target of 10% was modeled using the following procedure. First, the effective SINR of a UE was modeled according to [24] as;

$$\mathrm{SINR}_{\mathrm{eff}}(\mathrm{uid}, d) = \min\{\mathrm{SINR}(\mathrm{uid}, d), \mathrm{SINR}_{\mathrm{threshold}}\} \quad (12)$$

where $\mathrm{SINR}_{\mathrm{eff}}(\mathrm{uid})$ is the effective SINR of a UE for mapping to corresponding CQI and TBS. $\mathrm{SINR}(\mathrm{uid}, d)$ is the SINR as a result of the UE's instantaneous channel conditions as in Eq. (11). And $\mathrm{SINR}_{\mathrm{threshold}}$ is the SINR value corresponding to the 26 MCSs level. The mapping of SINR to TBS was modeled as follows:

$$\mathrm{TBS}(\mathrm{uid}, d) = \mathrm{TBS}(\mathrm{SINR}_{\mathrm{eff}}(\mathrm{uid}, d)) \quad (13)$$

where TBS(uid,d) is the TBS in bits allocated to UE based on $\mathrm{SINR}_{\mathrm{eff}}(\mathrm{uid})$.

In LTE, there are 7 OFDMA symbols in a resource block (RB) and TTI of 0.5×10^{-3} s. For two RB pairs, the TTI is 1×10^{-3} s and number of subcarriers is 12 [22]. Hence, the number of symbols in an RB is equal to 7 multiplied by 12 which is 84 in TTI of 0.5×10^{-3} s and 168 in TTI of 1×10^{-3} s for an RB pair. The number of bits in an RB is the number of symbols multiplied by the number of bits per symbol. The number of bits per symbol is the modulation index multiplied by the coding rate which is the symbol efficiency. Therefore, the number of bits in an RB pair is the symbol efficiency multiplied by 168, and this is the TBS. Therefore, data rate (R) for a UE i is given according to [22] as follows:

$$R(i) = \frac{\mathrm{TBS}(i) \times \mathrm{NRB}(i)}{\mathrm{TTI}}(1 - \mathrm{BLER}(i)) \quad (14)$$

where $\mathrm{TBS}(i)$ is the physical transmission block information capacity (in bits) for the CQI state I, and $\mathrm{BLER}(i)$ is the average block error rate (BLER), TTI is the transmission time interval and $\mathrm{NRB}(i)$ is the number of resource block allocated to UE i. The achievable data rate for each UE has been modeled based on instantaneous channel conditions. Therefore, from Eq. (14), the data rate $R(\mathrm{uid}, d)$ delivered to a UE (*uid*) placed at distance d from the eNB assuming constant targeted BLER was modeled as follows:

$$R(\mathrm{uid}, d) = \frac{\mathrm{TBS}(\mathrm{uid}, d) \times \mathrm{NRB}(\mathrm{uid}, d)}{\mathrm{TTI}}(1 - \mathrm{BLER}) \tag{15}$$

Hence, putting the value of $\mathrm{NRB}(\mathrm{uid}, d)$ of macro and pico UE from Eqs. (9) and (10), respectively, the data rate for macrocell UE and picocell UE was modeled as follows:

$$\mathrm{RMUE} = \frac{\mathrm{TBS}(\mathrm{uid}, d) \times \mathrm{NRB}_{\mathrm{macro}}(h)}{\mathrm{TTI}}(1 - \mathrm{BLER}) \tag{16}$$

$$\mathrm{RPUE} = \frac{\mathrm{TBS}(\mathrm{uid}, d) \times \mathrm{NRB}_{\mathrm{Pico}}(h, k)}{\mathrm{TTI}}(1 - \mathrm{BLER}) \tag{17}$$

where RMUE and RPUE are the data rate for UE connected to macrocell and picocell, respectively. Therefore, the total data rate within a macro area coverage was modeled as follows:

$$\mathrm{RallUE} = \sum \mathrm{RMUE} + \sum \mathrm{RPUE} \tag{18}$$

where RallUE is the total data rate. Therefore, from Eq. (18), the average macro area throughput and average UE throughput was modeled as follows:

$$\text{Average Macro Area Throughput} = \frac{\mathrm{RallUE}}{\mathrm{NumCell}} \tag{19}$$

$$\text{Average UE Throughput} = \frac{\mathrm{RallUE}}{\mathrm{NumUE}} \tag{20}$$

where NumCell is the total number of MeNB and NumUE the total number of UE.

4.2 *Energy Efficiency Model*

Assuming static power consumption irrespective of traffic load situations, the base station power consumption is defined as in [19] by:

$$\mathrm{Pc}_i = \mathrm{Nsec\ Nant(Ai\ PTX + Bi)} \tag{21}$$

where Nsec and Nant denote the eNBs's number of sectors and the number of antennas per sector, respectively. Pc_i is the average total power per base station, and PTX is the power fed to the antenna as in Eq. (3). The coefficient Ai accounts for the part of the power consumption that is proportional to the transmitted power, which includes radio frequency amplifier power and feeder losses. While Bi denotes the power that is consumed independently of the average transmit power which includes signal processing and site cooling [19]. The energy efficiency is defined as the ratio of the total data rate (RCi) delivered within a cell and power consumption of the cell (Pci), which is defined as in [19] by:

$$\mathrm{EE}_{\mathrm{Ci}} = \frac{\text{overall data rate}}{\text{total power consumed}} = \frac{\mathrm{RCi}}{\mathrm{PCi}} \tag{22}$$

where RCi is the overall data rate in bits/s within a cell, and PCi is the total power consumption of the cell in watts and $\mathrm{EE}_{\mathrm{Ci}}$ is the transmission energy efficiency for all UE in bits/joule within the cell. Therefore, from Eq. (22), the total transmission energy efficiency for HetNet was modeled as follows:.

$$\mathrm{EE}_{\mathrm{HetNet}} = \frac{\mathrm{RallUE}}{\mathrm{Pc}_{\mathrm{macro}} + \mathrm{Pc}_{\mathrm{pico}} \times \mathrm{k}} \tag{23}$$

where RallUE is the total data rate obtained using Eq. (18). $\mathrm{Pc}_{\mathrm{macro}}$ and $\mathrm{Pc}_{\mathrm{pico}}$ are the power consumption of MeNB(s) and PeNB(s), respectively, obtained using Eq. (20), while k is the number of PeNB per macrocell. Also from Eq. (23), the transmission energy efficiency of macrocell and picocell was modeled as follows:

$$\mathrm{EE}_{\mathrm{macro}(i)} = \frac{\mathrm{RMUE}}{\mathrm{Pc}_{\mathrm{macro}}} \tag{24}$$

$$\mathrm{EE}_{\mathrm{pico}(i)} = \frac{\mathrm{RPUE}}{\mathrm{Pc}_{\mathrm{pico}}} \tag{25}$$

where $\mathrm{EE}_{\mathrm{macro}(i)}$ is the energy efficiency of macrocell in bits/joule, $\mathrm{EE}_{\mathrm{pico}(i)}$ is the energy efficiency of picocell in bits/joule. $\mathrm{Pc}_{\mathrm{macro}}$ is the power consumption of MeNB in watts, $\mathrm{Pc}_{\mathrm{pico}}$ is the power consumption PeNB in Watts. The average energy efficiency is given as follows:

$$\mathrm{AV.EE} = \frac{\sum \mathrm{EE}_{\mathrm{HetNet}}}{\mathrm{NumCell}} \tag{26}$$

where AV.EE is the average energy efficiency in bits/joules, NumCell is the number of macrocells.

4.3 Load Balancing Fairness Measure

The total number of UEs in a MeNB area comprises of UEs connected to MeNB and UEs connected to PeNB(s). The same frequency is reused in the MeNB and PeNB, and using round-robin resource allocations, equal time resources are assigned to each UE. Therefore, it is expected that the average MeNB (MUE) throughput and average PeNB UE (PUE) throughput given as U_M and U_P, respectively, is the same for optimal load balance between MeNB and PeNB(s) according to [2]. Hence, the load balancing fairness index U_K is formulated as follows:

$$U_K = |U_M - U_P| \tag{27}$$

where $|U_M - U_P|$ is the difference between the average MeNB (MUE) throughput and average PeNB UE (PUE) throughput or vice versa. The smaller the value of U_K the more balanced the system load distribution between MeNB and PeNB.

5 Description of Proposed Energy-Efficient Bias Setting

In the conventional BRSRP cell selection algorithm, fixed bias values are set. Due to varying load condition in each cell of a mobile wireless HetNet, fixed bias setting will lead to poor network performance [11]. It will only make sense if the bias value is set based on current traffic load. Therefore, an improved cell selection algorithm is proposed to dynamically set bias value based on estimated energy efficiency as a load metric. The algorithm efficiently estimates the varying load in each cell, then, based on the estimated load, a bias value is set per cell. This will ensure that an optimized energy efficiency and traffic balance are achieved in the HetNet system.

The proposed algorithm requires that transmission energy efficiency for different bias values (α) is first estimated, and then the bias value that yields the optimal energy efficiency is configured per cell. It is noteworthy that energy efficiency is estimated for every network realization, but adaptive bias configuration is carried out only when an energy efficiency optimality gap is exceeded. This is to ensure that frequent handover especially for cell edge UE is avoided. The optimality gap (λ) is modeled as the ratio of the absolute difference between the energy efficiency associated with configured bias (EE_H) and measured energy efficiency (EE_M). The energy efficiency optimality gap is expressed as follows:

$$\lambda = \left(\frac{|\mathrm{EE}_H - \mathrm{EE}_M|}{\max(\mathrm{EE}_H, \mathrm{EE}_M)} \right) * 100 \tag{28}$$

where EE_H is the energy efficiency of the bias value initially configured, and EE_M is the new energy efficiency measured for each network realization. The higher the difference between EE_H and EE_M or vice versa the higher the value of λ, and the higher the value of λ the more significant change between the estimated energy efficiency and the previous value of energy efficiency. Therefore, for a small value of λ, the current bias value remains unchanged else the process of adaptive configuration is initialized to obtain the new bias value that yields an optimized performance. In this chapter, the value of λ was set to be 10%. This value was obtained after running several simulation runs, and worst case was considered for the same number of UE to mitigate frequent handover.

There must be a limit to the value of CRE bias to be selected even though a larger value of bias yields high offloading gain; however, the larger the bias value the poorer the SINR of picocell edge UEs [2]. In the proposed algorithm, 16 dB is considered as the maximum CRE bias value β_n. This is because the difference between MeNB and PeNB transmit power is 16 dB. CRE bias interval of 3 dB is considered to minimize the number of bias values for each network realization. This is done to avoid frequent handover and reduce simulation time. This means for each network realization energy efficiency for each of the bias values will be estimated and stored with the corresponding bias value. The bias value that yields the overall highest energy efficiency will be automatically configured on the PeNB. The bias value will be configured per macro area coverage and it will be implemented by the MeNB. Therefore, PeNB(s) in the same macro area coverage will have the same bias value and will be controlled by the MeNB following similar procedure with the X-2-based handover [26]. The energy efficiency estimation will be carried out periodically such that as the load condition varies, the network will automatically adapt a new bias setting that will yield optimized performance.

The input to the proposed algorithm is acquired from the network side. The proposed method is similar to the CRE-based cell selection which is employed in the 3GPP standard. In both methods, the RSRP measurement and CRE bias values are used to consider the best serving cell. The novelty in this chapter is the development of an adaptive CRE bias setting using energy efficiency as cell load metric. Algorithm 1 further explains the process of adaptive bias setting.

```
Algorithm 1: Energy Efficient Adaptive Bias Setting
initializations
$\beta_n = 1:3:\beta_n max$, $EE_{TH} = 0$
    For k = 1: Number of Drops
        For u = NumUEs
            For m = NumMeNB
                Calculate UE $RSRP_m$ according to eqn (3)
                For n = NumPeNB
                Calculate UE $RSRP_p$ according to eqn (4)
                    If $RSRP_m > RSRP_p + \beta_n$
                      MeNB UE
                Else
                    PeNB UE
              End
            Compute SINR for all UEs according to eqn (11)
        End
    Compute PeNB throughput according to eqn (16)
Compute PeNB energy efficiency according to eqn (24)
```

```
18.0   End
19.0   Compute MeNB throughput according to eqn (17)
20.0  Compute MeNB energy efficiency according to eqn (25)
21.0  End
22.0   Compute overall energy efficiency according to   equation (26)
23.0   If $\beta_n$ < $\beta_n$max
24.0      Increment $\beta_n$ by 3 and repeat step 1.0 to 23.0
25.0        Else
26.0        End
27.0          Compute $\lambda$ according to eqn (28)
28.0            If $\lambda$ < 10%
29.0            Repeat 1.0 to 28.0
30.0              else
31.0             Configure bias with highest energy efficiency
32.0   Compute load balance fairness according to eqn (27)
33.0               End
34.0 End
```

6 Scenario Description and Simulation Assumption

Based on the 3rd Generation Partnership Project (3GPP) LTE system level simulations toolbox defined in [27], a system of seven wraparounds sectored MeNB (21 cells) with four PeNB per sector is considered in this chapter. The PeNBs are randomly dropped within a MeNB area with minimum inter-site distance constraints. Each sector has a directional antenna at 120° apart one for each sector, while the PeNB has an omni-directional antenna. Users are uniformly distributed throughout the coverage area. Mobility is represented by users having different locations in each drop. Other related system level simulation parameters are specified in Table 1.

6.1 Propagation Models

For this chapter, single antenna receivers and transmitters are assumed, and therefore, only large-scale parameters are considered in the channel model according to [25].

$$P_{\mathrm{RX}} - P_{\mathrm{TX}} = \mathrm{PL} + \mathrm{SF} + G_A + L_{\mathrm{misc}} \tag{29}$$

where P_{RX} and P are the received and transmit powers,respectively, and PL and SF are the path loss and fading due to shadowing, respectively. The directional antenna gain is given as G_A and L_{misc} is any miscellaneous loss such as feeder cable loss. The path loss and shadow fading are carrier frequency dependent, and UE communication link is either line of sight (LoS) or non-line of sight (NLoS) depending on whether the location of the UE is indoor or outdoor. The path loss models of MeNB and PeNB are expressed by Eqs. (30) and (31), respectively, according to [25].

Table 1 System level simulation parameters

Parameter		Setting/Description
Cell layout		7 Hexagonal MeNBs; 3 sectors; reuse 1
MeNBs radius		500 m
Bandwidth and carrier frequency		10 MHz at 2000 MHz
Number of PeNBs per sector		4
Hotspot radius		40 m
Minimum distances between	MeNBs and PeNBs	75 m
	Among PeNBs	40 m
	MeNBs and UE	35 m
	PeNBs and UEs	10 m
Transmission power	MeNBs	46 dBm
	PeNBs	30 dBm
Path loss	MeNBs	$128.1 + 37.6 \log_{10}$ (r [km]) [24]
	PeNBs	$140.7 + 36.7 \log_{10}$ (r [km]) [24]
Number of UEs per sector		10, 20, …, 100
UE distribution		Uniform distribution [27]
Packet scheduler		Round-Robin
Power consumption parameters		Macro: Ai = 21.45; Bi = 354.44, Pico: Ai = 5.5; Bi= 38 [19]

$$128.1 + 37.6 \log(r[\text{km}]) \tag{30}$$

$$140.7 + 37.6 \log(r[\text{km}]) \tag{31}$$

where r is the three-dimensional (3D) distance between the UE and the MeNB or PeNB which is expressed as follows:

$$r = \sqrt{a^2 + b^2} \tag{32}$$

where the absolute antenna height difference between an eNB and a UE is denoted by b and a, respectively, is the two-dimensional (2D) distance between an eNB and a UE.

6.2 Antenna Patterns

The 3-sector antenna pattern used for each sector, reverse link and forward link is specified according to [25] by:

$$A\theta = -\min\left[12\left(\frac{\theta}{\theta_{3\mathrm{dB}}}\right)^2, A_{\mathrm{m}}\right] \tag{33}$$

θ is defined as the angle between the direction of interest and the boresight of the antenna, is the 3 dB beamwidth in degrees, and A_{m} is the maximum attenuation. For a 3-sector scenario, $\theta_{3\mathrm{dB}}$ is 70°, and A_{m} is 20 dB.

7 Results and Discussion

This section evaluates the performance of the proposed adaptive bias setting and draws comparisons with the existing cell association techniques. The metrics to be compared are the connection proportion of UEs to PeNBs, SINR, load balancing fairness using the difference between average UE throughput for PeNB and MeNB [2], MeNB area throughput and average UE throughput and energy efficiency, respectively.

7.1 Proportions of UEs Connected to PeNB

The simulation was carried out for different number of UEs for the HetNet configuration 1. The proposed adaptive bias setting has the highest proportions of UEs connected to the PeNBs when 10 UEs per cell were allowed into the network, after which the BRSRP with 6 dB bias maintains the highest, as shown in Fig. 2.

This is due to the offloading of more UEs from MeNB to PeNBs as a result of the effect of pico CRE associated with BRSRP and the proposed adaptive bias. The proportion of UEs connected to PeNB for BRSRP with bias of 6 dB is about 10% higher than the conventional RSRP for the different number of UE simulated, whereas, for the proposed adaptive bias, it is about 15% for 10 UE per cell, about 5% for 20 and 30 UE per cell, after which there is no significant difference with RSRP. This implies that as the number of UE increases, the proposed adaptive bias tends to configure smaller bias values.

For the proposed adaptive bias, the proportion of PeNB UEs decreases for up to 20 UEs in the system, but allowing up to 30 UEs into the system; however, the connection ratio stabilizes. Therefore, it can be deduced that the best offloading gain for the proposed adaptive bias is achieved when 10 UEs are allowed in the system.

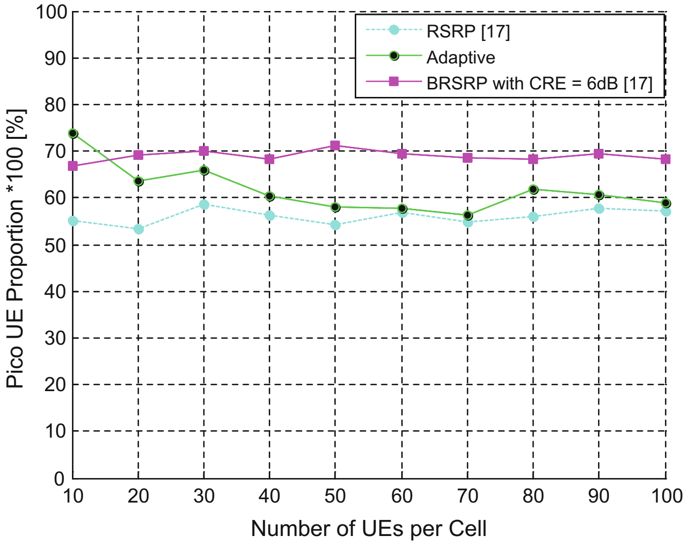

Fig. 2 PeNB UE proportion

Nevertheless, for both RSRP and BRSRP with 6 dB bias, the connection ratio does not show a significant difference in all the number of UE considered.

7.2 SINR CDF

The cumulative distribution functions (CDF) of the SINR of BRSRP with 6 dB bias and the proposed adaptive bias with 4 PeNBs lie slightly above the SINR CDF of RSRP as the reference cell association scheme, as shown in Fig. 3.

The worst affected UE by interference in all the cell association schemes is the cell edge (worst 5%) UE categories according to [2]. Essentially, any offloading due to increase in PeNB cell range will result in SINR performance degradation of the offloaded UEs. This is due to the interference effect suffered by picocell edge UEs from the high transmission power of MeNBs. Consequently, the SINR CDF for the cell edge UEs of the BRSRP with 6 dB was found to be slightly worse than the SINR CDF of the RSRP. Nevertheless, the proposed adaptive bias shows no significant difference with the RSRP. This shows that, with the proposed adaptive bias, the picocell edge UEs will not be in an outage; however, with BRSRP and larger bias value, the picocell edge UEs will be in an outage.

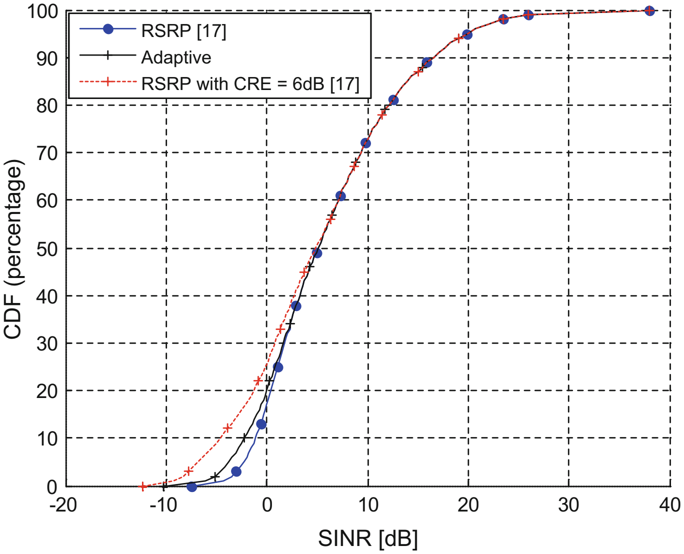

Fig. 3 The CDF of SINR

7.3 Average UE Throughput as Load Balancing Fairness Measure

Even though the proposed adaptive bias improves the traffic load balance in the system when compared with RSRP, RSRP with a bias of 6 dB exhibited a more balanced average UE throughput performance between PeNB and MeNB. The difference between the average throughput performance of the PeNB UEs and MeNB UEs is 5.32, 3.62 and 1.6 Mbps for RSRP, proposed adaptive bias and BRSRP with 6 dB, respectively, as shown in Fig. 4.

Hence, BRSRP with 6 dB has the lowest difference in the average UE throughput between the MeNB UEs and PeNB UEs, which shows a more balance in the system's load condition.

7.4 Throughput Performance

For all the traffic load considered, the average UE throughput and average macrocell area throughput decrease with the proposed adaptive bias and BRSRP with a bias of 6 dB as depicted in Fig. 5.

This can be attributed to the fact that BRSRP and the proposed adaptive bias essentially offload UE from MeNB to PeNB, and the larger the bias the more the offloading gain. Therefore, large bias tends to overload the PeNB thereby lowering the

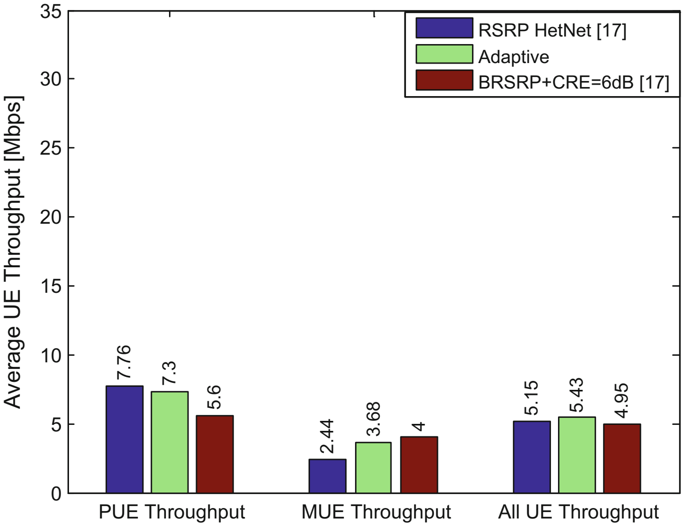

Fig. 4 Average UE throughput for 30 UE per cell

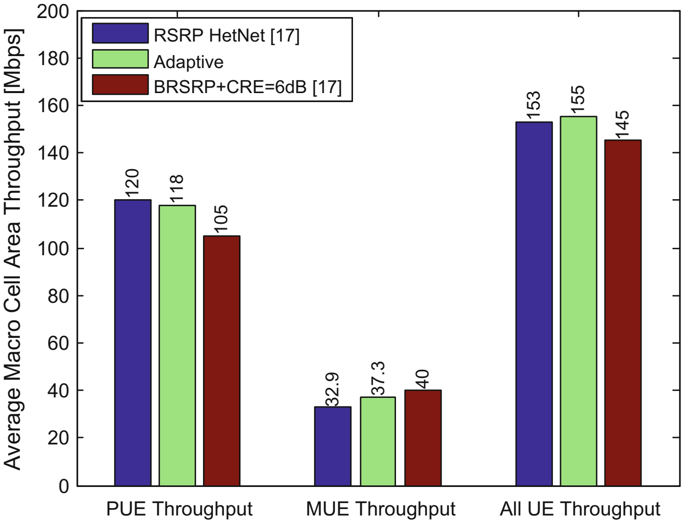

Fig. 5 Average macrocell area throughput for 30 UE per cell

average achievable throughput of the PUE due the round-robin scheduler employed. The round-robin resource allocation makes UEs share the limited resource blocks in the picocell equally. Also as the bias increase, picocell edge UE increase, such UEs are greatly impacted by interference from MeNB which consequently reduce their rate. Conversely, the average UE throughput and average macrocell area throughput increase with the proposed adaptive bias and BRSRP with a bias of 6 dB. 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 higher throughput.

Even though BRSRP with 6 dB bias achieves the best traffic load balance, it has the worst average UE throughput and average macrocell area throughput performance for the traffic load considered. This can be attributed to poor SINR performance with 6 dB and redundancy introduced to the MeNB due to limited UE allowed in the MeNB as a result of biasing. It can also be observed that the proposed adaptive bias achieved the best average UE throughput and average macrocell area throughput. This is because the proposed adaptive bias was able to dynamically configure an optimized bias that maximizes throughput and energy efficiency. However, the proposed adaptive bias and RSRP achieve a poor traffic load balance. This is due to low offloading of UEs from PeNB to MeNB.

7.5 Energy Efficiency Performance

The proposed adaptive bias achieved the best energy efficiency for all the traffic load simulated as depicted in Fig. 6.

BRSRP with 6 dB achieved the worst energy efficiency due to poor SINR performance which lowers the total achievable throughput. The PeNB have very high energy efficiency compared to MeNB. This can be attributed to the fact the PeNB utilizes a lower amount of power due to its small area coverage and delivers higher throughput due to its lower path loss. On the other hand, the MeNB utilizes a higher amount of power due to large area coverage and delivers lower throughput due to higher path loss. Consequently, the energy efficiency of HetNet is greatly impacted by the high power consumption of the MeNB.

8 Conclusion

HetNet deployment has the potential to improve capacity as well as energy efficiency. However, cell selection based on BRSP with fixed bias limits the energy efficiency in LTE-Advanced HetNet. Therefore, in this chapter, an energy-efficient adaptive bias setting strategy is proposed to dynamically configure bias using energy efficiency as a cell load metric. The energy efficiency was modeled as a ratio of data rate to base station power consumption. Thus, the power consumption is evaluated using

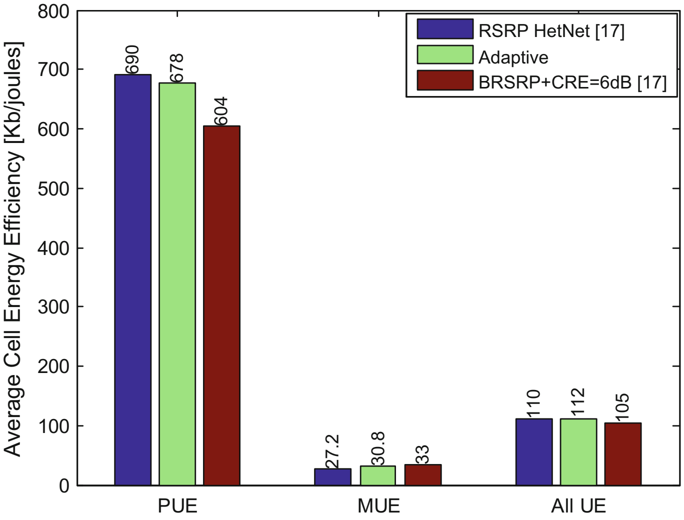

Fig. 6 Average macrocell area energy efficiency

power consumption parameters while the system capacity was modeled based on link adaptation, considering spatial distribution of UEs. From simulation results, it was found that the proposed adaptive model achieves an improved energy efficiency, average UE throughput and system capacity by 6.7, 9.7 and 6.9%, respectively, when compared with BRSRP with a fixed bias of 6 dB as benchmark algorithms. The proposed adaptive bias improves traffic to load balance in the system when compared with RSRP. However, BRSRP with a fixed bias of 6 dB performs better in terms of traffic load balance between PeNB and MeNB.

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