Improving Load Balancing in Various User Distribution LTE Advanced HetNets through a Hybrid Channel-Gain Access-Aware Cell Selection Scheme

Ajagbonna Babatunde Emmanuel[1], Abdoulie Tekanyi[1], Man Yahaya[1] and Mohammed Aliyu Gadam[2]

[1]Department of Electrical and Computer Engineering, Ahmadu Bello University, Nigeria.

[2]Electrical Engineering Department, Federal Polytechnic Bauchi.

spbabt@gmail.com

Abstract—**Long Term Evolution (LTE)-Advanced Heterogeneous Networks (HetNets) deployment was introduced to address the increasing demand for Quality of Service (QoS), high data rates, and coverage extension. However, load balancing still remains a critical problem in HetNets. Adopting the conventional Reference Signal Receive Power (RSRP)-based cell selection in HetNets causes most user equipment (UE) to connect with the Macro eNodeBs (MeNBs) due to their higher transmit power as against that of the Pico eNodeBs (PeNBs), thus leading to serious load imbalance in HetNets. Therefore, this hybrid algorithm combined the channel gain-aware and the access-aware cell association metrics as a single metric for UE to base station association in LTE-Advanced HetNets deployment scenarios. The scenarios considered are the HetNets configuration 1 and configuration 4b. The developed Hybrid Channel Gain Access Aware (HCGAA) scheme improved load balancing performance by 25.4% and 12.1%, respectively, compared with the 3GPP RSRP and Reference Signal Receive Power plus Cell Range Expansion (RSRP +CRE) cell selection scheme. Also, an enhanced pico connection ratio of up to 40.2%, which is 21.3% more than that of the RSRP and RSRP +CRE cell selection schemes was achieved by the HCGAA algorithm. These improvements translate to the efficient utilization of the network resource and prevent crowding of certain cells in the network.**

Index Terms— **Cell Selection; Heterogeneous Networks; Load Balancing; Pico Connection Ratio; Uniform And Hotspot LTE Configurations.**

I. INTRODUCTION

Following the exponential increase in the demand for data rate and the large number of connected devices (which include smart phones, tablets, laptops, cameras, sensors, and smart home), it is clear that network operators need to find sustainable ways to address the constraints of diverse services [1]. For a given coverage, in comparison to the deployment of fewer large eNBs, the deployment of a large number of small eNBs, in which each requiring lesser power and located closely to users, reduces the energy consumption [2]. This necessitated the introduction of HetNets by the 3GPP.

Therefore, to serve the increasing traffic, HetNets consisting of small cells like pico cells in macro cell layer to enhance capacity and coverage were introduced by 3GPP in order to meet the International Mobile Telecommunication-Advanced (IMT-A) requirements for the 4G [3]. A HetNet, as shown in Figure 1, is a multi layer network comprising of different types of base stations (macro, micro, pico, and femto) that have different transmission powers and coverage areas, with the sole aim of improving the overall network energy efficiency [4]. Picocells are mostly preferred in the HetNets because of the ease of planning and deployment [5].
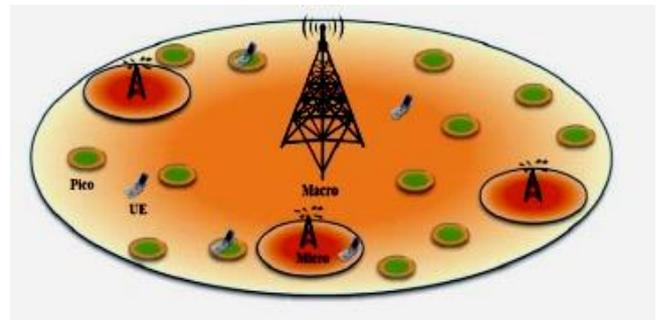

Figure 1:HetNet Deployment [4]

However, the diversity among different base stations breeds several new challenges that may significantly impact the spectral efficiency performance. For instance, during cell selection process in a HetNet, most users prefer to associate with the MeNB with the RSRP based associations scheme due to the diverse transmit powers of different base stations. This results in the uneven distribution of traffic load among different base stations and in turn the underutilization of the resources of the low power base stations [6]. Due to the low transmission power of the small eNBs, if the RSRP based cell association technique is applied in HetNet deployments, the MeNB is overloaded, in comparison to the PeNB because only a few users would connect to the small cells. Thus, the available resources of the small cells would not be fully exploited while at the same time in the macro cell, the competition for the available resources would remain high [7].

To prevent traffic load imbalance, a fixed biased cell association scheme was developed [8]. However it lacked information on the type of resource allocation employed in the cell and also failed to detect changes in traffic load condition in either the PeNBs or the MeNBs; hence, it could not proportionally upload the traffic load for improved system performance. In [9], the authors developed a path

loss based cell association scheme that allows UE to be connected to base stations that have the smallest path loss. Due to their small radius and proximity, this scheme resulted in more UE to be connected to PeNBs, thus causing underutilization of the MeNB. The RSRP association scheme and channel access cell association metrics were combined to achieve a balanced network [6]. However, the assumption that the MeNB is always congested is not always the case, as there are situations where the PeNBs are hotspot congested. More recently, a prioritized load balancing technique for UE in a HetNet was developed based on a fixed channel gain threshold and access to nodes schemes. UE with channel gain greater than the defined threshold connected with the node provides the maximum channel gain, whilst its channel gain is combined with the access probability to the node [10]. However, the simulation scenario did not represent a realistic UE distribution and the threshold selection criterion was not stated.

In this research paper, the load imbalance problem in a HetNet is solved by combining a user to base station association algorithm that is based on the channel gain between the UE and the base stations, and the access probability to the base stations. The access-aware (access probability) was formulated as the reciprocal of the number of UEs in a cell to prevent UE from connecting to cells that are overcrowded. Thus, cell association was derived as a function of the number of UEs exists in a cell. Then, extensive simulations were performed using MATLAB 2013a for both uniform UE distribution and hotspot UE distribution scenarios and the results show that the developed HCGAA algorithm performs better than the RSRP and RSRP+CRE based on the cell association in terms of load balancing fairness and pico connection ratio.

The remainder of this paper is organized as follows. In Section II, the background of the various cell association schemes is presented. Section III presents the system model and basic metrics. Implementation of the developed algorithm is presented in section IV. Section V provides the simulation result and discussions and the conclusion is presented in Section VI.

II. BACKGROUND

Cell selection entails the procedure through which UE is attached to either PeNB or MeNB using the received signal strength assigned to resources for traffic offloading. Cell selection can thus achieve traffic load balancing and throughput maximization of the UE by using the available resource allocated [11]. Some major cell selection schemes are:

A. Title, Maximum Reference Signal Received Power based Cell Association

The RSRP from base stations is used to determine the appropriate base station to associate UE in a network. At the time of cell selection, UE gets associated with the base station providing the highest RSRP. So, the ith UE selects the kth base station as its serving base station if,

$$CellID_i = arg_k max(RSRP_k) \qquad (1)$$

In a HetNet, the maximum RSRP scheme makes UE to always be associated with the base station, thus providing the highest SINR. As such, most UE prefer to associate with

the high power base stations because of its greater transmit power, as seen in Figure 2 [12]. This results in the uneven distribution of traffic load among different base stations and in turn underutilization of the resources at low power base stations [13].
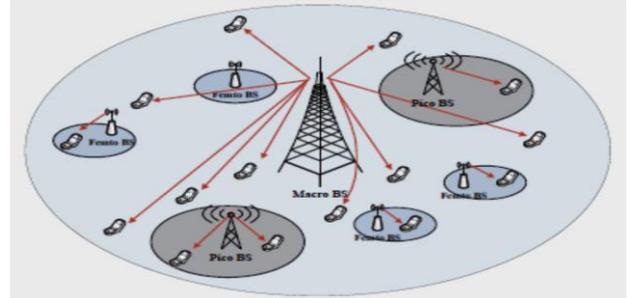

Figure 2: RSRP based Cell Association of a Three-Tier HetNet [12].

B. Cell Range Expansion based Association

The coverage area of a PeNB and the association opportunity for UE to connect to the PeNB is increased by adding a positive bias value to the RSRP from PeNBs, as shown in Figure 3 and is given by [14]:

$$Cell\ ID_i = arg_k max(RSRP_k + bias_k) \qquad (2)$$

where, *bias* is zero for the macro cell and has a non-negative value for the small cells, resulting in more users association with the smaller cells. As seen from Figure 3, a positive bias is added to the RSRP from the PeNB, closed to the PeNB UE1 in order to extend its coverage and enable PeNB1 to associate with it.
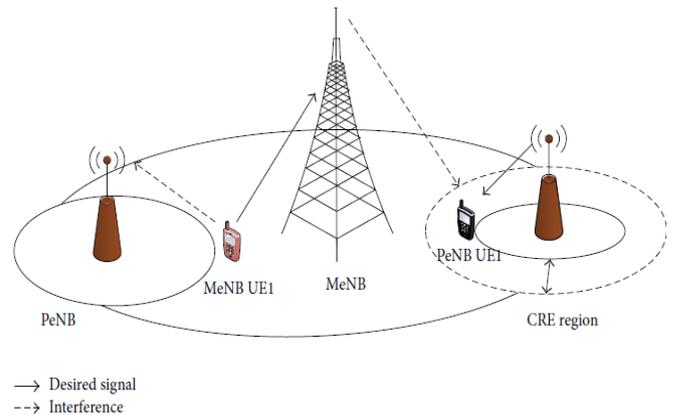

→ Desired signal
--→ Interference

Figure 3: Cell Range Expansion based Association [15].

III. SYSTEM MODEL AND SIMULATION SET UP

The considered simulation environment in this paper is based on the 3GPP LTE system level simulations toolbox, having 19 hexagonal wrap around cells (57 MeNBs). Each of the cells has three sectors with each sector considered an active LTE eNodeB having 4 PeNB per sector. The PeNBs are randomly dropped within the sector with minimum inter-site distance constraints. A hexagonal cell has 3 directional antennas at 120 degrees apart, one for each MeNB sector and the PeNB has one omni-directional antenna. The scenarios considered are the HetNets configuration 1 with uniform user distribution, which comprises of 4 PeNBs and 25 uniformly distributed UEs and configuration 4b of hotspot distribution, which comprises of 4 PeNBs and 30 UEs, two-third of which are clustered around the PeNBs as

defined by the 3rd Generation Partnership Project (3GPP) standard. The schematic representation of HetNet configuration 1 and configuration 4b is shown in Figure 4 and Figure 5, respectively. Mobility is represented by users having different locations in each drop.
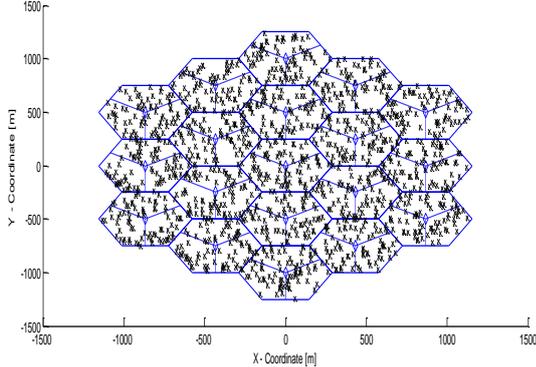

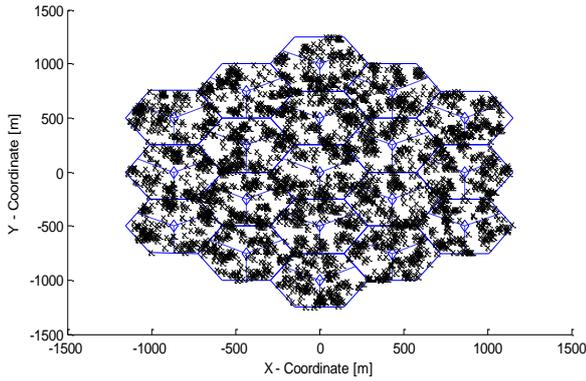Figure 4: Schematic Diagram of HetNet Configuration 1 [16]

Figure 5: Schematic Diagram of HetNet Configuration 4b [16]

A. Load Balance Model

Load balancing belongs to the group of suggested self-organising network functions for LTE network operations, which is meant to deliver extra gain in terms of network performance. Load balancing is achieved by adjusting the network control parameters in such a way that the overloaded cells can offload the excess traffic to the low-loaded adjacent cells, whenever available [17].

Jain's Fairness index is employed to measure the status of the system's load balance. It is a load balance index measuring the degree of load balancing of the entire network and it is given as follows [10]:

$$\rho(t) = \frac{(\sum \sigma_{k(t)})^2}{|M|\sum(\sigma_{k(t)})^2} \tag{3}$$

where, $\rho(t)$ is the fairness in the load balance, $\sigma_{k(t)}$ represents the load in any cell k, and M represents the total number of MeNB and PeNB in the system.

B. Pico Connection Ratio

The pico connection ratio is the number of UE connected to the PeNBs divided by the total number of UE in the network, after the selection process. If after the cell selection process, the number of UEs connected to pico cells is n_{pc} and the total number of UEs in that HetNet is N_{het}, the pico connection ratio is given as:

$$P_{CR} = n_{pc}/N_{het} \tag{4}$$

where, P_{CR} represents the pico connection ratio.

IV. HYBRID CHANNEL-GAIN ACCESS-AWARE CELL SELECTION SCHEME

The hybrid algorithm is a combination of the channel gain cell selection algorithm and access aware cell association algorithm. An access probability, which is the inverse of the number of user in a cell when the adopted round robin scheduling is combined with the channel gain and used as the association metric to prevent the overload of an eNB and to ensure full utilization of the resource of the eNBs. The channel gain between an eNB and a UE in the downlink is given as the difference between the receive power and the transmit power. The power is transmitted from the base station to the UE. These powers are mathematically related as [18]:

$$G_P = P_R - P_T \tag{5}$$

where, G_P is the channel gain, P_R is the receive power at the UE and P_T is the transmit power at the base station. When G_P is negative, it signifies a loss.
In a large scale fading environment, the transmit signal that passes through before getting to the UE constitutes the channel gain, which is given as [19]:

$$G_P = -PL + SF + AG - Lmisc \tag{6}$$

where, PL represents the path loss between the base station and the UE, SF is the shadow fading, AG represents antenna gain, $Lmisc$ is any residual miscellaneous loss such as attenuation in the RF feeder cables or outdoor in-car loss.
The path loss and shadow fading vary with carrier frequency and distance, whether the UE is indoor or outdoor and whether the UE link is in line of sight or non line of sight. Path loss and shadow fading are known as slow fading [19].
Path loss is the dissipation of the transmit power as it travels towards the receiver. Path loss is also the result of the effect of the propagation channel, while shadowing occurs as a result of the various obstacles the transmit signal encounters due to absorption, scattering, diffraction, and reflection.

The access probability using round robin resource allocation for UE connecting to MeNB and PeNB is given as [6]:

$$p_m^A = \left(\frac{1}{N_m+1}\right) \tag{7}$$

$$p_p^A = \left(\frac{1}{N_p+1}\right) \tag{8}$$

where, p_m^A and p_p^A are the probability of UE associating with the MeNB and PeNB, respectively and N_m and N_p are the number of UEs in the MeNB and PeNB, respectively.
In HetNets, the same spectrum is reused in MeNBs and PeNBs and when round robin scheduling is employed, equal time resources are assigned to each UE, hence, the load in a cell can be represented by the number of UE in that cell [20].The hybrid cell selection algorithm metric for UE to connect to the MeNBs and PeNBs are given as:

$$Hybrid_m = G_P \times \left(\frac{1}{N_m+1}\right) \qquad (9)$$

$$Hybrid_p = G_P \times \left(\frac{1}{N_p+1}\right) \qquad (10)$$

Therefore if $Hybrid_p$ is greater than $Hybrid_m$, the UE is connected to the PeNB, or else it is connected to the MeNB. The input to the algorithm is acquired from the network side. The algorithm is implemented in the MeNB and executed through the X-2 interface.

Steps of the Hybrid Channel-Gain Access-Aware (HCGAA) Cell Selection with Interference Mitigation Algorithm

The steps taken to implement the HCGAA cell selection algorithm are:

Step 1: Initialization of parameters: Configure simulator input, generate MeNB topology, generate pico topology, and generate UE topology.

Step 2: Compute channel gain between UE an eNB using (5).

Step 3: Compute pico and macro access probability using equation (7) and (8) respectively.

Step 4: Compute $Hybrid_m$ and $Hybrid_p$ using (9) and (10) respectively.

Step 5: If $Hybrid_p$ is greater than $Hybrid_m$, connect UE to PeNB else connect UE to MeNB.

Step 6: Compute Jain's fairness load balancing index using (3)

Step 7: Compute pico connection ration using (4)

V. SIMULATION RESULT AND DISCUSSIONS

In the following, we compare the performance of the conventional RSRP, RSRP + CRE bias of 4dB, channel gain, and the developed HCGAA cell selection algorithm for HetNet scenarios (configuration 1 and configuration 4b). For the RSRP + CRE, a 4dB bias is used in order not to incur serious interference. Load balance fairness and pico connection ratio were used to evaluate the performance of the algorithms.

A. Load Balancing Fairness

The Jain fairness load balance index for the RSRP, RSRP+CRE, Channel gain and HCGAA algorithms were computed and plotted for HetNet scenarios (configuration 1 and configuration 4b). This metric value was computed after the cell association process. The graph of the Jain fairness load balance index with 4 PeNB and the increasing UE for configuration 1 is depicted in Figure 6. With 45 users as shown, the HCGAA load balancing performance is 25.4% , which is 12.1% better than that of the RSRP and RSRP +CRE schemes, respectively. It is observed that the load balancing index increases as the number of users increases for the HCGAA and the channel gain aware cell selection scheme, while for the RSRP and RSRP + CRE, the load balancing performance drops as the numbers of users increases. This indicates that the HCGAA scheme is better in terms of load balancing and can be implemented in densely populated areas.
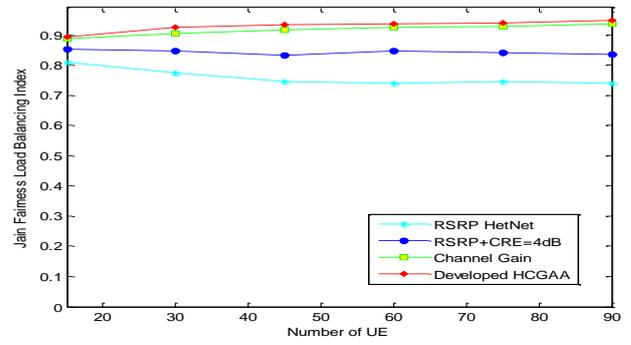

Figure 6: Jain Load Balancing Index with 4 PeNBs and Increasing UE for Configuration 1

For configuration 4b, it is observed that the load balancing index of the HCGAA and RSRP +CRE schemes show a slight identical load balancing performance. With 4 PeNBs and 45 users as shown in Figure 7, the improvement of the HCGAA cell selection scheme over that of the RSRP and RSRP +CRE schemes is by 5.3% and 1.5%, respectively.
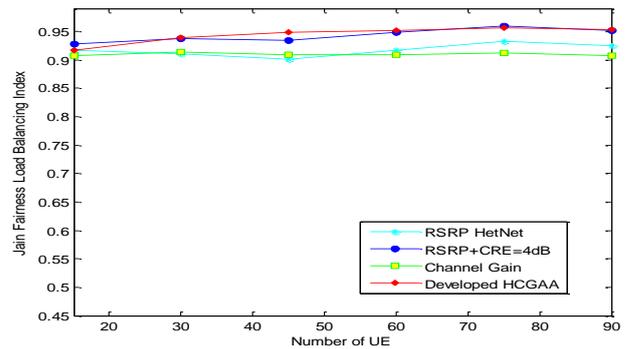

Figure 7: Jain Load Balancing Index with 4 PeNBs and Increasing UE for Configuration 4b

The graphs of the Jain fairness load balancing index with fixed number of UE and increasing PeNBs for configuration 1 and configuration 4b are depicted in Figure 8 and Figure 9, respectively.
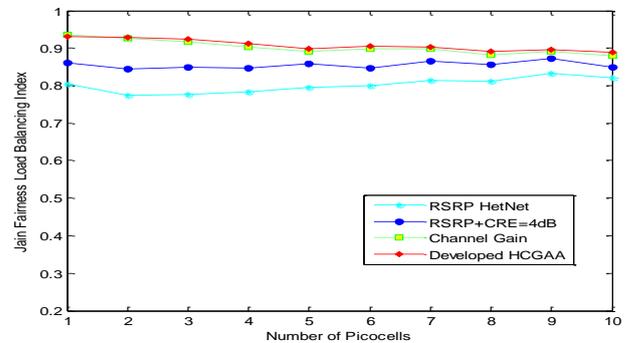

Figure 8: Jain Load Balancing Index with 25 UE and Increasing PeNBs for Configuration 1
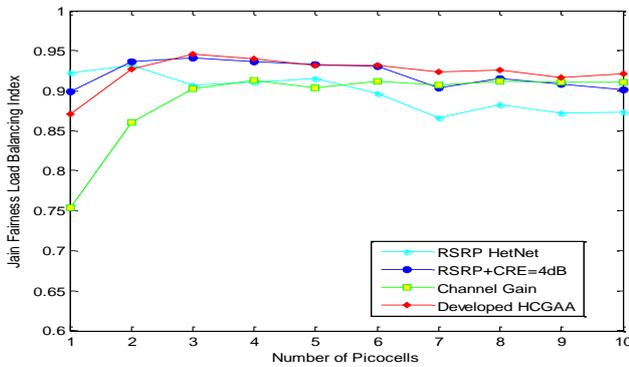
Figure 9: Jain Load Balancing Index with 30 UE and Increasing PeNBs for Configuration 4b

From Figure 8, with 25 users, the load balancing performances of all the schemes slightly drop for configuration 1 as the number of PeNB increases. However, for configuration 4b, the load balancing index of the schemes starts depreciating when the number of PeNB is 3 for the HCGAA and RSRP + CRE schemes and 2 for the RSRP scheme, as depicted in Figure 9. For configuration 1, with 7 PeNBs and 25 UE as shown in Figure 8, the load balancing performance of the HCGAA is 10.7%, which is 4.2% better than the RSRP and RSRP +CRE schemes, respectively. Also, for configuration 4b, the improvement over the RSRP and RSRP +CRE schemes is by 6.7% and 2.1%, respectively. These results show that a hybrid cell selection scheme that utilizes the channel gain metric and the access probability of connecting to a base station together as the cell association initiator, places the users more evenly than other association schemes. Thus, with the HCGAA scheme, cells are not over loaded or underutilized as in the RSRP and RSRP +CRE schemes.

B. Pico Connection Ratio

The pico connection ratio was computed for the various schemes. It is the number of UE connected to the PeNBs divided by the total number of UE in the network, after the the selection process. The graphs of the pico connection ratio with 4 PeNB and the increasing UE for configuration 1 and configuration 4b are depicted in Figure 10 and Figure 11, respectively.
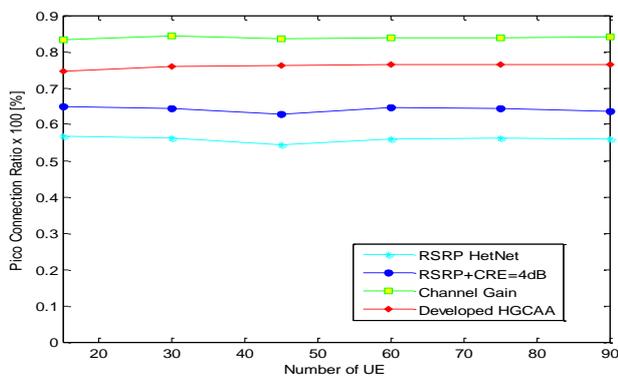

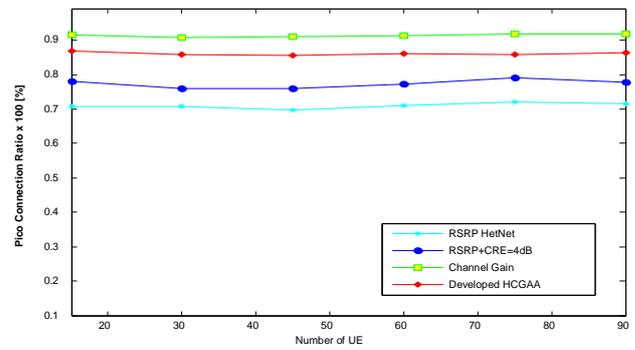Figure 10: Pico Connection Ratio for 4 PeNBs with Increasing UE for Configuration 1

Figure 11: Pico Connection Ratio for 4 PeNBs with Increasing UE in Configuration 4b

For configuration 1 and 4b, with 4 PeNBs, the pico connection ratios of the various cell association schemes remained fairly stable as the number of UE increases, as shown in Figure 10 and Figure 11, respectively. However, the pico connection ratio is the highest for the channel gain cell selection scheme for both configuration 1 and 4b because the UEs are generally closer to the PeNB than the MeNB and utilizing only the channel gain as the cell selection criteria, makes more UE to connect to the PeNBs. Therefore, utilizing channel gain scheme implies smaller path-loss and higher channel gain at the User Equipments (UEs). This makes more UEs to be connected to the PeNBs. For configuration 1, with 4 PeNBs and 45 UE, the pico connection ratio of the channel gain cell selection scheme is 53.7% and 40% more than that of the RSRP and RSRP +CRE schemes, respectively, while pico connection ratio of the HCGAA scheme is 40.2%, which is 21.3% more than that of the RSRP and RSRP +CRE schemes, respectively. For configuration 4b, also with 4 PeNBs and 45 UE, the pico connection ratio of the channel gain cell selection scheme is 30.3%, which is 19.9% more than that of the RSRP and RSRP +CRE schemes, respectively, while the pico connection ratio of the HCGAA scheme is 22.6%, which is 12.7% more than that of the RSRP and RSRP +CRE schemes, respectively.

The graphs of the pico connection ratio for fixed number of UEs and the increasing PeNBs for configuration 1 and configuration 4b are depicted in Figure 12 and Figure 13, respectively.
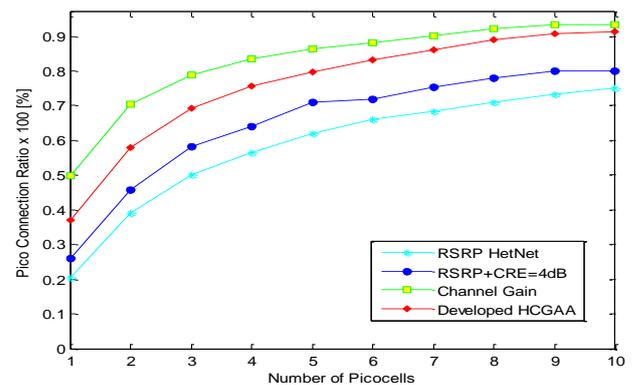

Figure 12: Pico Connection Ratio for 25 UE with Increasing PeNBs for Configuration 1
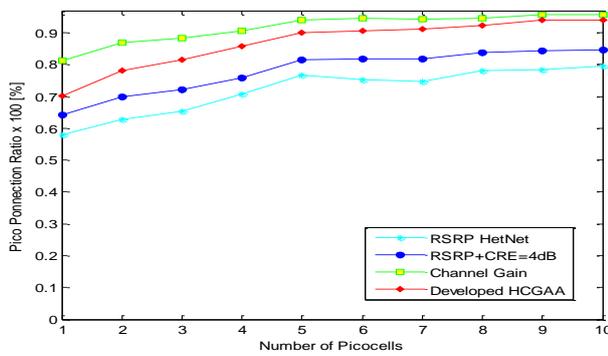
Figure 13: Pico Connection Ratio for 30 UE with Increasing PeNBs for Configuration 4b

When the number of UE is fixed, it is discovered from Figure 12 and Figure 13 that the pico connection ratios of the cell selection schemes increase as the number of PeNBs increases for configuration 1 and configuration 4b. For configuration 1, with 7 PeNBs and 25 UE, the pico connection ratio of the channel gain cell selection scheme is 31.7%, which is 19.8% more than that of the RSRP and RSRP +CRE cell selection schemes, respectively, while the pico connection ratio of the HCGAA scheme is 25.9%, which is 14.6% more than that of the RSRP and RSRP +CRE cell selection schemes, respectively. For configuration 4b, and with 7 PeNBs and 30 UE, the pico connection ratio of the channel gain cell selection scheme is 25.9%, which is 14.6% more that of the RSRP and RSRP +CRE cell selection schemes, respectively, while the pico connection ratio of the HCGAA scheme is 30%, which is 11.7% more than that of the RSRP and RSRP +CRE cell selection schemes, respectively.

It is observed from Figure 12 and Figure 13 that the pico connection ratio of the channel gain aware scheme is higher than that of the HCGAA cell selection scheme. This is due to the proximity of pico cells to the UEs, thus utilising only the channel impediments as the association criteria causes more UEs to be connected to the pico cells. The data obtained from Figure 12 and Figure 13, show how the channel gain and HCGAA scheme offload more traffic to the PeNBs after the cell selection process as compared with the RSRP and RSRP+CRE cell selection schemes.

VI. Conclusion

In a multi-tier Hetnet deployment comprising MeNBs and PeNBs, cell association suffers great unbalanced traffic load problem. The diverse transmission power of the MeNBs and PeNBs makes the conventional RSRP based cell association not viable because it causes more UE to be connected to the MeNBs, thereby causing traffic load imbalance. The unbalanced load situation results in the underutilization of the available resources of the PeNBs. In this research paper, we developed and implemented a hybrid algorithm to improve load balancing in a uniform and hotspot user distribution LTE-Advanced HetNet by combining the channel gain association and access probability of connecting to a cell as a single metric for UE to cell association. The developed HCGAA scheme improved load balancing fairness and pico connection ratio as compared to the standard 3GPP RSRP and RSRP +CRE cell selection algorithm.

Other researchers can study the impact of interference on load balancing and energy efficiency of the HCGAA scheme. Other cell selection algorithms based on data rates and distance aware can be employed in cell selection criteria.

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