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Intercell Interference Mitigation in LTE-Advanced Heterogeneous Network

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Abstract

In order to fulfill 4G requirements, deploying low power nodes (LPN) within a macro cell layout, also known as heterogeneous networks (HetNets), is a promising solution to enhance overall system performance, performance at cell-edges and indoor coverage. LTE/LTE-Advanced system uses Orthogonal Frequency Division Multiple Access (OFDMA) method to cater services to multiple users simultaneously. Due to the orthogonal character of these sub-carriers, the interference between sub-carriers is eliminated within a cell but reuse of these sub-carriers in adjacent cells creates intercell interference. HetNets deployment includes new technical challenges related to increased interference level and throughput degradation; in particular, cell edge users of low power cell are vulnerable to strong interference from high power macro cells. Inter-cell interference coordination/enhanced intercell interference coordination (ICIC/eICIC) schemes in frequency, time and power domain can be used to overcome these intercell interference issues. In macro-pico deployment scenario, cell range expansion (CRE) method is used to offload more users to pico cells for traffic load balance and time domain eICIC technique called Almost Blank Subframe (ABS) method is used to overcome interference to users in cell edge of low power pico cells. The heterogeneous network performance in terms of average User Equipment (UE) throughput, peak UE throughput, Cell throughput and UE SINR for cell edge has improved significantly as compared to homogeneous network.

Keywords

LTE – LTE-Advanced – HetNets – Interference – ICIC/eICIC – ABS

1. Introduction

Cellular system deployment has reached practical limits in many dense urban areas while data traffic only continues to increase. Network operators are revisiting conventional cellular system topologies and are considering a new paradigm called heterogeneous networks. Heterogeneous networks consist of planned macro base station deployments that typically transmit at high power overlaid with several low power nodes such as Pico base stations, distributed antennas, Femto base stations, and relays. The low power nodes are deployed to eliminate coverage holes in outdoor and indoor environments and also to increase the capacity/area of the network. Picocells and Femtocells are new small base stations installed in hotspots to increase the coverage and capacity. [1]

Heterogeneous Networks (Hetnets) have been introduced in the LTE-Advanced standardization in order to provide a significant network performance leap when other advanced technologies (CA, MIMO, and CoMP) are unable to achieve that, as they are reaching theoretical limits. Such techniques may not always work well either, especially under low SINR conditions, where received powers are low due to attenuation and/or interference might be high, whereas HetNets can do. Complementing macro cells with LPNs and dedicated indoor solutions based on the 3GPP standard is a good approach to meet the predicted requirements for higher data rates and additional capacity. This approach can include the use of picocells, femtocells, relays and remote radio units (RRUs), which delivers high per-user capacity and coverage in areas covered by LPNs, with the potential to improve performance in the macro network by offloading traffic generated in hotspots. By adding LPNs to the existing macro layer, the operator creates a two-layer cell structure with eNodeBs of different types called Heterogeneous Network, heterogeneous in the deployment sense. HetNets improve the overall capacity as well as provide a cost-effective coverage extension and higher data rates to hotspots by deploying additional network nodes within the local-area range. In addition, they also increase overall cell-site performance and cell-edge data rates by bringing the network closer to end users. The larger number of eNodeBs allows for more efficient spectrum reuse. [1]

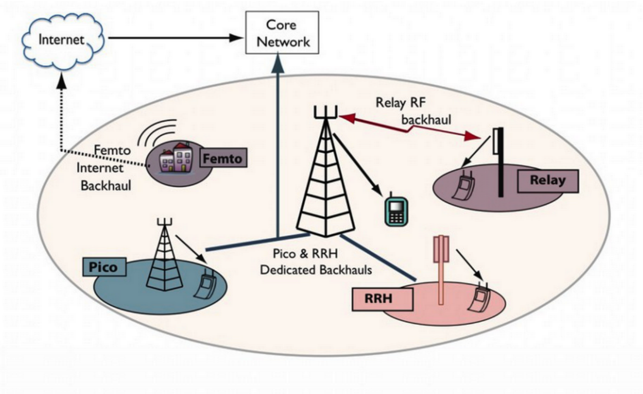

Figure 1: Heterogeneous network deployment scenario

Table 1: Specifications of different network elements in HetNets [1]

Typical Node	Typical Transmit Power	Coverage
Macro Cell	46 dBm	Few Km
Pico Cell	23 - 30 dBm	<100 m
Femto Cell	<23 dBm	<50 m
Relay	30 dBm	300 m
RRU	46 dBm	Few Km

Unbalanced Coverage

Nodes with different transmission powers can result in the unbalanced coverage between uplink and downlink. The downlink coverage of the macro eNodeB is much larger than the coverage of the pico eNodeBs because of larger transmission power. However, the transmission power difference of macrocell and picocells does not affect the coverage in the uplink because the UE is the transmitter and the transmission powers of all UEs are approximately same. Thus, the eNodeB that provides the best downlink coverage may be different from the eNodeB providing the best uplink coverage. [1]

Cell Selection Method

In the traditional cell selection method, UEs can select the serving cell by comparing the maximum Reference Signal Received Power (RSRP) of macro eNodeBs and pico eNodeBs. The cell with higher RSRP is selected as a serving cell.

Serving Cell = argmax (RSRP_i) for all i belongs to I,

Where i represents the eNodeB and I is the set of macro eNodeB and pico eNodeBs.

However, in HetNets, cell selection based on the strongest downlink RSRP is not the best strategy because UEs will be connected to a higher power node instead of the lower power nodes at the shortest path loss distance. New cell selection techniques are required to address the problems caused by nodes with different transmission power. One technique is to add an offset value to the RSRP received from pico eNodeB such that the UE preferentially selects a pico eNodeB as the serving cell even when it is not the strongest cell. This technique is known as Cell Range Expansion (CRE). [2]

Cell Range Expansion

LPNs coverage is quite limited by its transmission power and the strong interference from macro cells, which means that only a small percentage of users can benefit from LPN deployment, specially in cell edges. This leads to a state of coverage unbalance and for that, a new technique was required to increase HetNets efficiency, offload the more macro cell traffic, i.e. attract more UEs to LPNs and solve the UL and DL coverage unbalance. Moreover, the performance of LPNs is significantly improved if UEs are allowed to connect to a weaker SINR LPNs, which refers to extend LPNs boundaries for load balancing purposes. With RE, the serving cell of a UE is selected from the set of neighbor cells as:

Serving Cell = argmax (RSRP_j + Bias_j) for all j belongs to J,

Where RSRP and Bias are expressed in dB and j represents pico eNodeB and J is the set of pico eNodeBs. Now, a UE does not necessarily connect to the eNodeB that has the strongest DL received power. [1] [2]

2. Intercell Interference

In Orthogonal Frequency Division Multiple Access systems, the radio spectrum is split into a large number of channels, referred to as sub-carriers. Data transmission is performed simultaneously over multiple sub-carriers, each carrying a low-rate bit stream. OFDM is part of the downlink air interface in the fourth generation cellular systems based on 3GPP long term evolution (LTE). OFDMA sub-carriers are orthogonal to each other. As a result, intra-cell interference is not present. Inter-cell interference, on the other hand, becomes a performance-limiting factor. For this reason, interference mitigation has become an important topic in performance engineering of OFDMA networks. The simultaneous use of the same spectrum between different cell layers that run on different values of transmit power creates interference that will become more severe compared to homogeneous networks. For picocells, cell-edge user experience high level of intercell interference from macro eNodeB in downlink. [2] [3]

2.1 Intercell Interference Coordination (ICIC)/ Enhanced Intercell Interference Coordination (eICIC)

The LTE/LTE-Advanced system includes ICIC (Intercell Interference Coordination) techniques which enable the Evolved Node B(eNodeB), via the X2 interface (eNodeB to eNodeB/pico eNodeB), to pass overload and high interference information. These informations help eNodeB to dynamically adjust the number and power of physical resource blocks (PRBs) allocated in a cell.

In a LTE heterogeneous network, small cells such as pico- and femtocells are deployed within the coverage area of macrocells to increase network capacity and handle non-uniform UE traffic distribution. The deployment of small cells potentially enhances the throughput performance by providing extra cell-splitting gain, specially for the UEs on macrocell edges and in hotspots. On the other hand, it may lead to increased interference in the network and thus reduce UE throughput. The interference is more significant when the small cells are deployed on the same carrier as the macrocells. It is therefore important to coordinate the interference between the macro- and pico cells in order to maximize the benefit Hetnets. The enhanced inter-cell interference coordination (eICIC) techniques that are standardized in 3GPP LTE-Advanced Release 10 for small cell deployments deal with interference issues in HetNets, and mitigate interference on traffic and control channels using power, frequency and the time domain. [4]

2.1.1 Typical Deployment Scenario

One of the most important features in LTE Release 10 is the support of heterogeneous network deployments, in which macrocells provide the basic coverage and small cells are deployed within the coverage area of macrocells to further enhance UE throughput. The following two typical small cell deployment scenarios are considered in Release 10: the macro–pico deployment and the macro–femto deployment.

Macro–Pico Deployment Scenario

In the macro–pico deployment scenario, picocells are deployed by the network operator in a planned way. For example, they can be placed on the edge of a macrocell or in a hotspot to enhance UE throughput. A Pico eNodeB (PeNodeB) that forms a picocell has the same protocol stack and functionalities as a Macro eNodeB (MeNodeB), but transmits with lower power. Both eNodeBs are connected to a Mobile Management Entity (MME) and a Serving Gateway (S-GW) via S1 interface. They are also connected to their neighboring MeNodeBs and PeNodeBs via X2-based backhaul. The X2 interface also facilitates the interference coordination between a macrocell and a picocell. [4]

In the macro–pico deployment scenario, a UE measures the downlink Reference Signal Received Power (RSRP) of its neighboring cells and chooses the one with the highest RSRP level as its serving cell. As a result, a picocell will serve a small number of UEs due to its low transmit power. In order to offload more data traffic to picocells, a logical bias can be added to the RSRP of the picocell before comparing it with the RSRP of another cell such as the macro. This biasing technique, called the Cell Range Expansion (CRE) bias, has been proposed to expand the serving area of a picocell without increasing its transmit power. An example is shown in figure 2 where PeNodeB 1 with positive CRE bias has a larger serving area than PeNodeB 2 which does not apply a CRE bias when the two PeNodeBs have the same transmit power. [5]

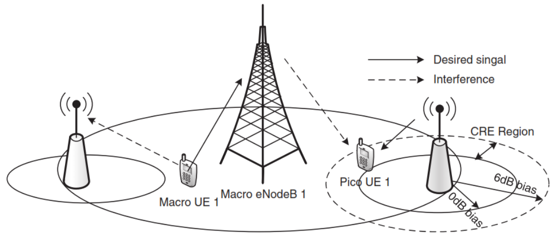

Figure 2: The interference situations in the macro-pico deployment scenario

The MeNodeB decides whether to hand over the UE to other eNodeBs based on the received RSRP measurement report. If the RSRP of a neighboring PeNodeB becomes larger than that of the MeNodeB, the MeNodeB will initiate the handover process of the UE by sending a HANDOVER (HO) REQUEST message to the PeNodeB via the X2 interface. After receiving the HO REQUEST message, the PeNodeB prepares radio resources for the UE and replies back to the MeNodeB with a HO REQUEST ACK message. The MeNodeB then sends a HO COMMAND message to the UE in order to initiate the acquisition process of the picocell. Meanwhile, the MeNodeB starts data forwarding to avoid any data loss. When UE completes the cell acquisition process, it informs the PeNodeB by sending a HO COMPLETE message. After receiving the HO COMPLETE message, the PeNodeB sends a RESOURCE RELEASE message to the MeNodeB via the X2 interface, which completes the whole handover process. [5]

2.1.2 Time Domain Techniques

There is a potential need of interference management in the downlink to avoid severe interference caused by macrocells in the macro–pico deployment scenario. The LTE Release 8/9 ICIC techniques work well for PDSCH interference management by frequency domain scheduling and resource partitioning. However, it is difficult to apply these techniques to the control channels and reference signals as they have fixed locations in the frequency domain. For example, the PDCCH spans the entire bandwidth in the first few OFDM symbols in each subframe. The need for interference mitigation of those control channels and reference signals is the main motivation of the eICIC techniques that were introduced in Release 10. [6]

Almost Blank Subframe (ABS)

The basic idea of the time domain techniques is to mute certain subframes of some cells in order to reduce the interference to the other cells. We call a cell that causes interference to UEs of another cell an aggressor cell and the latter the victim cell; the UEs that are interfered are referred to as the victim UEs. Ideally, the muted subframes configured by an aggressor cell should be totally blank (i.e. all REs are muted) in order to reduce the interference as much as possible. [7]

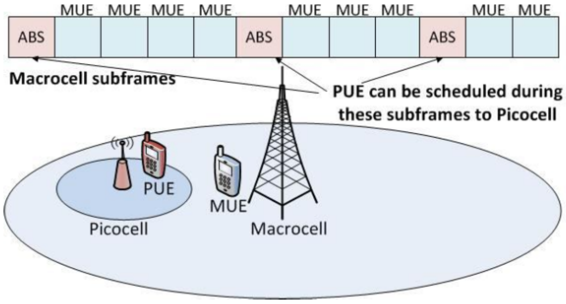

Figure 3: Almost Blank Subframes technique [4]

Consider the macro–pico deployment scenario, where the pico UEs in the CRE region of a picocell suffer strong interference from a macrocell. In the macro–pico deployment scenario, the expected behaviors of the macro and picocells are:

Step 1: The macrocell predicts that the traffic demand may exceed its capacity and it has to offload some UEs to the picocell.

Step 2: The macrocell hands over some UEs to the picocell by employing CRE.

Step 3: The macrocell mutes some subframes by configuring ABSs. These subframes are also called protected subframes from the context of the picocell.

Step 4: The macrocell informs the picocell of the ABS pattern via the X2 interface.

Step 5: The picocell schedules those UEs in the protected subframes based on the received ABS pattern. [4]

3. System Model and Methodology

We consider a three-cell LTE based wireless communication system model as shown in Figure 4. The system model consists of three adjacent uniformly distributed hexagonal cells in a two-dimensional coordinate system, each with equal radius of 500 m. Four Pico eNodeBs (PeNodeB) with cell radius 50 m are planned in the coverage of Macro eNodeB A's (Macro Cell A) coverage area. The PeNodeBs are low power nodes with maximum transmit power of 24 dBm and the transmitted signal from PeNodeB does not interfere the Macro UEs but the transmitted signal from MeNodeB interfere the Pico UEs in the downlink. Although Inter Cell Interference (ICI) is prominent in both uplink as well as downlink transmissions, this paper considers the study of ICI in the downlink transmission only.

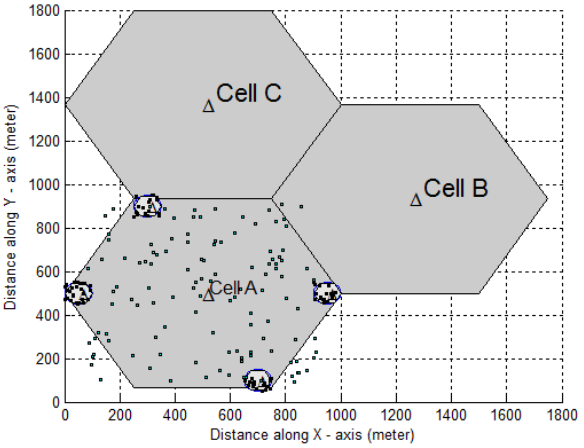

Figure 4: Macro-Pico layout with four Pico cells per Macro cell (Cell A)

The study is performed in cell A while Cell B and cell C are interfering cells. Each cell in the system model consists of an Macro eNodeB (MeNodeB) at the centre of the cell and each MeNodeB consists of a single omni-directional transmit and receive (TRx) antenna with 15 dBi gain covering the entire macro cell region. Similarly, all pico eNodeBs consists of a single omni-directional transmit and receive (TRx) antenna with 2 dBi gain covering the entire pico cell region. The signal transmitted from MeNodeB of cell A is the desired signal for the macro UE (MUE) located in cell A leaving the coverage area of pico cells.

Table 2: Network parameters and assumptions for Macro and Pico eNodeB

Parameters	MeNodeB	PeNodeB
Cellular Layout	Uniform	Non-Uniform
Cell Radius	500 meter	50 meter
Resource Partitioning	Reuse 1	Reuse 1
Carrier Frequency	2.0 GHz	2.0 GHz
System Bandwidth	20 MHz	20 MHz
eNodeB antenna Gain	15 dBi	2 dBi
BS Transmit Power	46 dBm	24 dBm
Thermal Noise	-174 dBm/Hz	-174 dBm/Hz
UE Power	23 dBm	23 dBm
UE antenna Gain	0 dBi	0 dBi

3.1 Related Formulations

The propagation path loss (PL) between a macro eNodeB and outdoor macro UE (MUE) located in a point P in the 2-dimension, at distance R in km from macro eNodeB, is modeled as:

$$PL(R) = 128.1 + 37.6log_{10}R \tag{1}$$

Similarly, propagation path loss (PL) between a pico eNodeB and pico UE (PUE) is modeled as:

$$PL(R) = 140.7 + 36.7log_{10}R \tag{2}$$

Where, PL(R) is expressed in dB and R in Km.

For all the UEs randomly distributed in the macro cell coverage area, the path loss can be computed using the equation 1. Similarly the received signal strength (RSS) can be computed using the formula;

$$P_{\mathrm{Rx}}(eNodeB) = P_{\mathrm{Tx}}(eNodeB) + GeNodeB + GUE - PL(R) \tag{3}$$

Where, P_{Tx}(eNodeB) denotes the eNodeB transmit power in dB, GeNodeB denotes the eNodeB antenna gain in dBi, GUE denotes UE antenna gain in dBi.

Signal to Interference plus Noise Ratio (SINR) is a key parameter that can describe the performance of a resource block allocation technique. As a general rule, the received signal power level at a UE decreases as it moves away from the centre of the serving cell. Thus, the SINR level of received signal decreases as the distance from the cell centre increases. Furthermore, as a UE moves towards the cell edge from the centre of the cell, the strength of the interference signals from the adjacent cells rises. Since, ICI levels are stronger at the edge of the cell, the SINR values of the actual transmitted signal is further reduced as the distance from the cell centre increases. The SINR at any point in a cell can be calculated by taking the ratio of actual signal strength and the strength of interferences from neighboring cells and noise (thermal noise) at that point.

$$SINR = \frac{P_{\mathrm{Rx}}(eNodeB)}{\sum_{\mathrm{Interferers}} P_{\mathrm{Rx}}(eNodeB) + P_{\mathrm{therm}}} \tag{4}$$

Where, P_{therm} is the thermal noise.

The effect of varying SINR can be used to estimate the maximum capacity of the channel by using the Shannon's channel capacity theorem, which is given by:

$$C = B * log_2(1 + SINR) \tag{5}$$

Where, C is the maximum channel capacity of the channel in bits/sec for the given SINR value. B is total bandwidth of the channel in Hz.

3.2 Methodology

Two different deployment scenarios are considered to evaluate the performance metrics. The first scenario is macro eNodeB only deployment scenario and the second scenario is macro-pico eNodeB deployment scenario (Hetnets).

Macro eNodeB only deployment scenario

Two important performance metrics i.e., SINR and the channel capacity, C for the entire user under consideration are evaluated using the equations (4) and (5). The cumulative distribution function (CDF) for SINR and throughput is computed and the CDFs are plotted against the SINR and average UE throughput.

Macro-pico eNodeB deployment scenario (Hetnets)

Two important performance metrics i.e., SINR and channel capacity, C for all the users that are under the coverage region of macro eNodeB are evaluated using the equations (4) and (5). Similarly, the SINR and channel capacity, C for all the users that are under the coverage region of pico eNodeB are evaluated using the equations (4) and (5). The cumulative distribution function (CDF) for SINR and throughput is computed by taking the macro-pico deployment as a combined system and the CDFs are plotted against the SINR and average UE throughput.

3.2.1 Procedure for Performance Comparison

Step 1: The performance metrics are calculated for macro only hexagonal cell network deployed homogeneously.

Step 2: Four pico cells are planned in the cell edge/hotspot area of the macro cell A as macro-pico heterogeneous network deployment scenario.

Step 3: The cell range expansion bias is applied to all the pico cells under consideration.

Step 4: The time domain eICIC method called Almost Blank subframe (ABS) is applied in macro-pico heterogeneous network deployment scenario to mitigate intercell interference between high power node and low power node at the cell edge of pico cells.

Step 5: The performance metrics are calculated for macro-pico heterogeneous network taking macro-pico deployment as a combined system.

Step 6: The comparison of performance metrics like UE average throughput, UE peak throughput, SINR of macro only homogeneous network and macro-pico heterogeneous network is carried out.

4. Result Analysis and Camparison

4.1 Cell Range Expansion (CRE)

The simulation is carried out for CRE of picocells with the bias value 0 dB, 6 dB, 12 dB and 18 dB. The CDF for SINR curves for different value of biasing shows degradation of SINR for those UEs offloaded to CRE region from macro eNodeB coverage area.

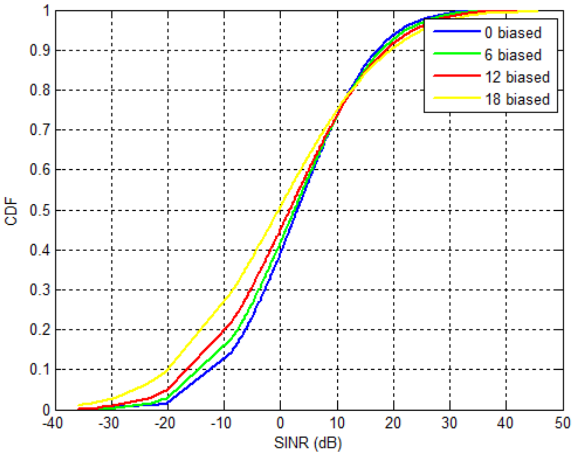

Figure 5: CDF curves for SINR for different bias value

4.2 Comparison of Throughput in Macro only and Macro-Pico Scenario

The average UE throughput is computed for macro only deployment scenario without considering the presence of pico cells. Then, the average UE throughput is computed for macro-pico deployment scenario by considering the presence of four pico cells within one macro cell. With the deployment of pico cells, there is significant increase in average UE throughput as there are only 10% of users with throughput greater then 2 Mbps in macro only scenario but there are 40% of users with throughput greater then 2 Mbps in macro-pico deployment scenario.

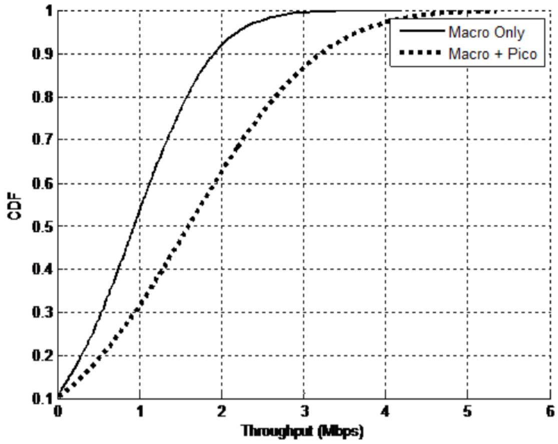

Figure 6: Comparison of CDF curves for average UE throughput

4.3 Comparison of SINR in Macro only and Macro-Pico Scenario

The SINR is computed for macro only deployment scenario without considering the presence of pico cells. Then, the SINR is computed for macro-pico deployment scenario by considering the presence of four pico cells within one macro cell by considering the macro-pico as a single system. With the induction of pico cells, there is significant increase in SINR for the cell edge user in macro-pico deployment scenario. At the same time, there is not much improvement seen for the SINR of cell center users as compared to the cell-edge users.

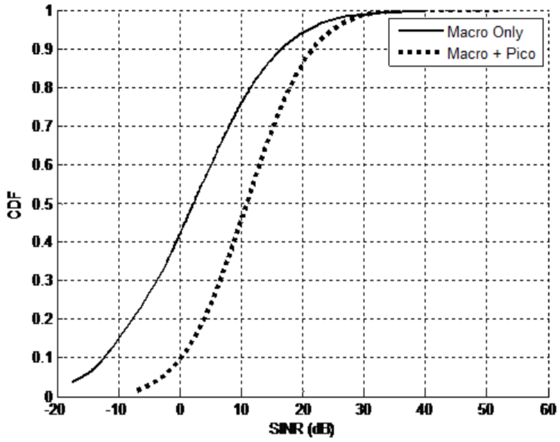

Figure 7: Comparison of CDF curves for SINR

4.4 Pico connection Ratio

As the bias is applied to the pico cell's RSRP, the coverage area of the pico cells increase that makes some of the macro UEs to offload to the CRE region of pico cells. The computation was made to calculate the pico connection ratio as the bias increased from 0 dB to 18 dB in steps of 6 dB. The rate of increase in pico connection also depends upon the number of active users. Similarly, the percentage of pico connections with the increase of pico cells per macro cell is also computed and obviously, with the more number of pico cells per macro cell, the percentage of pico UEs increases but after some number of pico cells, further addition of pico cells will not increase the number of pico UEs in the same rate. The reason for this is because of the fact that, with large number of pico cells, the CRE region of two or more pico cells may overlap and serve to the same user from CRE region.

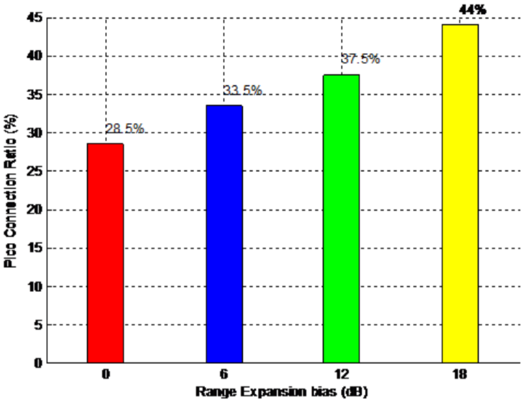

Figure 8: Range Expansion Bias Vs Pico Connection Ratio

5. Conclusion

Among all the available intercell interference coordination methods in frequency, time and power domain, the time domain technique has been implemented by maximizing the bandwidth utilization. Range expansion technique enhances the UL throughput, coverage and achieves traffic balance between macro and pico cell by offloading more UEs to pico cells, which is considered as a significant improvement of Hetnets deployment. However, with higher RE bias, interference issues become severe and that leads to a performance degradation in downlink, which is handled by the use of eICIC technique.

The performance analysis is carried out in macro-pico deployment scenario of heterogeneous network with four number of picocells in one macro cell layout. The time domain intercell interference coordination method with the use of almost blank subframes technique resulted into better cell edge throughput, increased peak throughput, improved SINR performance in cell edge and better coverage. The time domain eICIC has the freedom of frequency reuse factor of one and the whole bandwidth can be reused in all macro as well as in all pico cells. This resulted into optimum utilization of the available bandwidth for service provider and help to maximize the spectral efficiency.

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