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An Intelligent Pico Cell Range Expansion Technique for Heterogeneous Wireless Networks

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Abstract

Background/Objectives: Due to high transmission power emitted by macro cell, very few users will be offloaded to nearby pico cell which leads to underutilization of pico cells in Heterogeneous Networks (HetNet). **Method/Statistical Analysis:** Cell Range Expansion (CRE) is a technique to virtually expand the coverage range of pico cell. With the help of CRE, user equipment will add a bias value to actual signal strength received from pico cell and thereby offload their traffic from macro cell to pico cell. But, at the same time adding bias value will lead to additional downlink interference which becomes severe for choosing higher bias value. **Findings:** Optimal bias value reduces the number of outage mobile stations but it depends on several factors which are hard to find such as the distribution of mobile stations over the cells, resource shared between pico and macro cells, mobility pattern and so on. In this paper, we are proposing a solution of Intelligent Pico Cell Range Expansion (IP-CRE) which calculates the effective bias value for each mobile station independently, by using a fuzzy logic inference system. Our proposed solution takes multiple attributes like signal strength of pico and macro cells, speed and direction of mobile stations, battery level and traffic requirements as input parameters and the output will be an effective bias value for each mobile station. We analyzed the effectiveness of the bias value by varying the number of connected Pico cell User Equipment (PUE) in the expansion region. **Application/Improvements:** Our observations from the simulation experiments demonstrate that the proposed scheme reduces the number of outage UE and increases the number of offloaded UE in Het Net.

Keywords: Cell Range Expansion, Heterogeneous Networks, Intelligent System,Pico Cells, Small Cells

1. Introduction

Mobile data traffic is growing exponentially and the available spectrum for data applications is limited[1]. Operators have to manage their network efficiently to meet the customer needs. Deploying new modulation schemes and technologies with Heterogeneous Network (HetNet) is a solution to manage the huge traffic and thereby increase the spectral efficiency (bps/Hz/area). HetNet is a combination of both small and macro cells with different Radio Access Technologies (RAT)[2]. Macro cells having high transmission power are used to cover large area, and small cells are Low Power Nodes (LPNs), used to cover more users within a small area. There are different types of small cells: pico cells, femto cells, relay cells etc. Among these LPNs, a pico cell has greater advantage since it has the same backhaul as a Macro Base Station (MBS). In this research work, we assume that a User Equipment (UE) will associate with the base station that has the maximum Reference Signal Received Power (RSRP). Pico Base Station (PBS) transmission power varies from +23 to +30dBm, and it can serve tens of UE with a radius of coverage in hundreds ofmeters[3-6]. PBS range becomes smaller from hundreds of meters to tens of meters when PBSs are placed over the MBS. The transmission power of a MBS is about +40dBm and the transmission power difference between both base stations is about 16dBm. This large difference in transmission power can result in the reduction of PBS coverage area.

Cell Range Expansion (CRE) is a technique to

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virtually expand the region of small cells by adding a bias value to the Received Signal Strength (RSS). Bias value is generated by CRE technique to increase the number of UE connected to the PBS[7].The region which is expanded virtually by CRE technique is known as Expansion Region (ER) of the cell and it includes users of both MBS and PBS. PUEs located in ER gets DL interference since PUEs are connected with low signal strength compared to MBS signal strength. Macro cell User Equipment (MUE) located in ER gets UL interference and it is mostly depends on the UEs transmission power. In this article, we concentrate only on bias value which causes the DL interference for PUEs. Normally, PUEs will get high DL interference for higher bias values.

Inter Cell Interference Coordination (ICIC) techniques are introduced by 3GPP (third Generation Partnership Project) to control the interference between cells. ICIC techniques may be needed whenever CRE techniques are used (since it allows UE to connect with low signal strength). The bias value will be always a non-negative value. The two conditions of CRE where the UE will decide which Base Station (BS) to connect, is given below,

- If UE is connected to MBS, then

$$RSRP\ (MBS_{DL}) > RSRP\ (PBS_{DL}) + CRE\_bias \quad (1)$$

- If UE is connected to PBS, then

$$RSRP\ (MBS_{DL}) < RSRP\ (PBS_{DL}) + CRE\_bias \quad (2)$$

Where $RSRP\ (MBS_{DL})$, $RSRP\ (MBS_{DL})$ and CRE_bias represent the RSRP of MBS and PBS and range expansion bias value, respectively.

ICIC is about managing the resources between MBS and PBS whenever both base stations share the same resources between them. It is possible to implement ICIC technique since pico and macro base stations have strong backhaul[8]. ICIC techniques effectively stop MBS data transmission on some resources which is allocated at PBS. This is known as Almost Blank Subframe (ABS) in time domain approach[9]. However reference signals continue to be transmitted from the MBS, which causes DL interference to the PUE. In frequency domain approach, the interference is reduced by controlling the transmission power of a particular frequency at MBS which is already allocated to a PBS. When bias value increases the interference also increases correspondingly, therefore necessitatingthe need to arrive at an optimal bias value to control the interference. An optimal bias value reduces the interference, and increases the offloading rate. An optimal bias value depends on several factors like distribution of UE over the cell and the resource shared between base stations. Since the process of arriving at an optimal bias value is quite difficult, our proposed system gives an effective bias value which reduces the number of outages and increases the number of UE connected to PBS.

Section II investigates related work and different possible methods for CRE to obtain the expansion bias value. Section III explains the architecture of proposed intelligent CRE scheme. Section IV includes the simulation model and Section V gives the analysis of results. Final conclusion of the paper is added in Section VI.

2. Literature Survey

Underutilization problem of small cells can be addressed in two ways: at the base station or at the mobile station. At the base station, it can be implemented using multiple smart antennas to expand the region of small cells by controlling the transmission power of an antenna. At mobile station this is possible by virtually expanding the region of small cell by adding expansion bias value to the signal strength of small cells. In this paper we concentrate on the mobile station, since solution for the base station needs modification in existing infrastructure. Researchers by and large concentrate on mobile station side only[10-15]. The expansion bias value can be obtained either by centralized method or distributed method. In centralized method, expansion bias value is same for all UE. The expansion bias value is calculated and broadcast to all UE. In the distributed method, expansion bias value is different for different UE where each UE calculates it is own expansion bias value. Our proposed method is based on distributed method of obtaining the expansion bias value.

In[10] analyzed the benefits of range expansion with ICIC technique. Results shows that whenever range expansion and ICIC is provided to HetNet, the overall user capacity is increased. In[11] proposed a cell selection scheme with priority queue where pico cells get more priority. Whenever pico cells are available in the priority queue, the UE try to connect to the pico cell having the maximum RSRP. This may lead to load imbalance between macro cells and pico cells. Our proposed system selects cell depending on both RSRP and bias value which in turn depends on multiple attributes. In[12] analyzed DL performance of UEs with various bias values under CRE with ICIC technique. Results proved that the moderate bias settings enhance the user throughput. In[13] evaluated the performance of handover in CRE. Our proposed system considers velocity as one of the input to control the unnecessary hand over. Few methods to obtain the expansion bias valueare described below.

2.1 Fixed Bias Method

Fixed bias method is a traditional method where constant bias value is used for all mobile stations in the cell. The bias value may be calculated at base station and broadcasted to all mobile stations or preset to all mobile stations[14]. Each mobile station may have different requirements, hence a common bias value will not be effective for all mobile stations. When bias value is high, user throughput will decrease since all mobile stations will try to connect even though they are getting very low signal and interference also will be more. Our proposed intelligent system generates different bias values for different UE independently according to the needs of the each UE.

2.2 Based on Outages

In[15] proposed a scheme to determine the bias value for each UE by using Q-learning algorithm, where each UE learns the bias value that minimizes the number of outage UE from its past experience independently. Reinforcement learning algorithm is used for getting better bias value where the goal of the agent is to reduce the number of outage UE using Q-Learning algorithm. Simulation results show that the proposed scheme reduces the number of outage UE and improves network throughput.

This method is difficult to implement in real time since it is learning from the number of outage UE, which is calculated at base station side and broadcasted to all mobile stationsand number of the outages will vary according to number of UE present in the cell. Our proposed intelligent model is based on attributes like signal strength and battery level, thereby making it suitable to real time implementations.

2.3 Based on Traffic Demands

In[16] proposed a new scheme with rate-based CRE offsets in HetNet so that UE can decide on their associations based on their traffic demands. Each UE selects an appropriate cell according to the UE uplink traffic demand by using a rate-based CRE-offset mechanism. The UE with higher uplink traffic demands are assigned with a larger CRE offset. Their proposed model concentrates only on traffic demands, neglecting its battery level. It is important to protect the UE from power loss as well. Our proposed system considers both battery level and traffic demands of each UE.

2.4 Based On Resource Availability

In[17] proposed a model where cell range expanded according to the number of random access resource availability, thereby improving the average random access efficiency and the average random access delay. PBS coverage is extended by controlling the transmission power of PBS. Transmission power varies depending onthe difference between number of accessed UE and estimated number of UE. Since base station solution is costly, our proposed system uses mobile station solution.

3. Proposed System

Our proposed system generates effective bias value using fuzzy logic inference system which takes input as signal strength of PBS, battery life of UE, speed and direction of UE and traffic demands of UE. Depending on these multiple attribute values, different expansion bias values are generated for each UE independently. Fuzzy inference system can be classified into two types:Mamdani and Sugeno. Our proposed solution uses Mamdani type fuzzy logic inference system, where it maps input membership function to output membership function according to the defined rules[18]. Each input and output attribute has a three membership functions of low, medium and high. Intelligent engine takes inputs as normalized input values of each attribute. Input membership functions are mapped to output membership functions with help of fuzzy rules. Rules are designed to increase the utilization of small cells with basic properties of PBS.

3.1 Input Metrics

Our proposed intelligent system uses four input metrics to calculate the effective bias value.

3.1.1 Battery Level

Battery level of each UE is considered since this is a critical element in smart phone. PUE saves more power than MUE since MUEs spend more transmission power to transmit the data due to the relatively larger distance from MBS.

3.1.2 Speed and Direction of UEs

Speed and direction of each UE is considered since high velocity UE cause unnecessary association to PBS which reduces the system throughput. Moreover high velocity UE is not hotspot UE.

3.1.2.1 Traffic Demands

Our proposed system considers traffic demands as one of the input, since pico cells are good for UL rather than DL. Depending on the traffic demands of each UE, the bias value will be generated. Traffic Demands of each UE is calculated as below.

$$Traffic\ Demand = \frac{UpLink(UL)}{DownLink(DL)} \tag{3}$$

3.1.2.2 Signal Strength

Our proposed intelligent system considers signal strength of PBS and MBS as one of the input. CRE allows UE to connect with PBS with low signalcompared to MBS. As bias value increases, UE will connect to PBS with very low signals. This causes huge DL interference from MBS which leads to more data loss.

3.2 Proposed System Architecture

The proposed system (depicted in Figure 1.) consists of three main modules:

- Preprocessing module
- Offload decision making module
- Execution of offloadingmodule

3.2.2.1 Preprocessing

In the preprocessing module, each UE scans the network, detects all the pico cells available to UE by RSRP of each PBS. Thenecessary input information from the environment like signal strength of each PBS, speed and

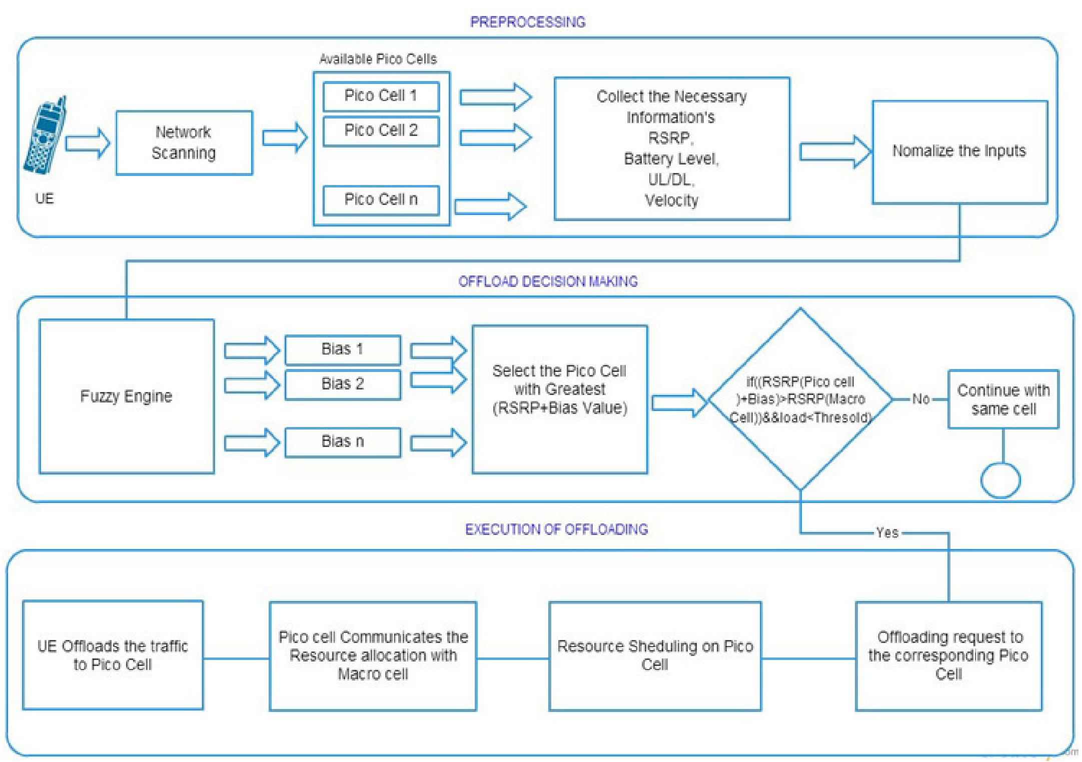

Figure 1. Architecture of IP-CRE.

direction, traffic demands and battery level of UE are collected. These input values are normalizedusing min-max normalization technique and they define the input membership functions for each attribute.

$$Normalize(Value)_{attribute} = \frac{Value - Min_{attribute}}{Max_{attribute} - Min_{attribute}} \quad (4)$$

3.2.2.2 Offload Decision Making

This module helps to make a decision whether to offload the traffic at a particular PBS or not. Intelligent system takes normalized values of each attribute as input. The fuzzy engine maps these values and generates the output bias value for each PBS independently, which helps to make the offloading decision for a particular PBS. This module is again subdivided into two main parts: Bias value generation and decision making.

- **Bias Value Generation**

Our proposed intelligent system is designed to increase the utilization of pico cells by increasing the numberof connected UE tothe PBS. Our proposed system uses fuzzy engine to generate the bias value for each UE. Fuzzy inference system has two main processes: fuzzification, followed by defuzzification. Fuzzification is a process of transforming crisp input values to membership function values for each attributes ranges from 0 to 1 of fuzzy interval. Defuzzification is an inverse process of fuzzification. It generates the crisp output value from the fuzzy sets. Since there is no standard for weight assignment in each attribute, we define the weights for each attribute. Fuzzy rules help to map the input membership functions to output membership functions. Rules are defined so as to increase the utilization of PBSwith its basic properties of a pico cell. Fuzzy engine generates the output as expansion bias value for each PBS, which is then given as input to the decision engine.

- **Decision Engine**

A decision engine is used to make the offloading decision for a particular PBS based on the expansion bias value. The decision engine adds the expansion bias value to the corresponding PBS received signal power as shown below:

$$(RSRP)\ PBS_i = (RSRP)\ PBS_i + Bias_i \quad (5)$$

In the above equation, denotes the received signal power of corresponding and denotes the corresponding bias value generated for the.The PBS with the highest value is selected from the list of available PBSs. When two or more values are same at the top, then the PBS with the higher original RSRP value is chosen.

Offloading decision is done by comparing the greatest RSRP of PBS with RSRP of MBS and load of corresponding PBS. If MBS has larger signal strength, then the UE will associate to the MBS, whereas,if has larger signal strength after the addition of bias value, and PBS load is also less than threshold, then UE will offload the traffic to this particular. Checking the load would help to reduce the PBS overloading and outages. Depending on these conditions, the offloading decision is made for a particular PBS. We evaluated the IP-CRE under two different situations, when the percentage of Resource Sharing (RS) between MBS and PBSs is known and when not known.

- For IP-CRE when RS is known,

$$((RSRP)\ MBS < (RSRP)\ PBS_i + Bias_i * PRS)\ \&\ \&\ (PBS_{iload} < Threaslold)) \quad (6)$$

- For IP-CRE when RS is unknown,

$$((RSRP)\ MBS < (RSRP)\ PBS_i + Bias_i)\ \&\ \&\ (PBS_{iload} < Threaslold)) \quad (7)$$

In the above conditions,the term PRS denotes the percentage of Pico Resource Blocks (PRBs) which is normalized in the range of 0 to 1. According to the condition in both situations, if true, then theUE will offload the traffic to any one PBS, otherwise the UE will continue with the same MBS.

3.2.2.3 Execution of Offloading

This module describes the offloading strategy to a particular PBS. There are two possible operations, depending on the decisions made.

- MUE can offload the traffic to any one PBS.
- PUE can offload the traffic to another PBS.

Depending on the decision made, the UE sends the offloading request to corresponding PBS. The PBS validates and accepts the request of UE. PBS uses a scheduling algorithm that schedules the Resource Blocks (RBs) for the particular UE and communicates the allocated RBs with MBS for reducing the DL interference[19]. The UE then offloads the traffic to the corresponding PBS. These operations can happen to any UE at any time in the cell. When there is no resource to be allocated or RSRPis very low, then the UE is considered to be an outage UE.

4. Simulation Model

Our proposed system IP-CRE is simulated in MATLAB with its fuzzy tool. In our simulation model, all UE are randomly distributed over the cell and each PBS is planted near the hotspots to cover the hotspots. The simulation parameters for the proposed system are depicted in the Table 1.

Each hotspot has 25 UE with it. The battery level will vary for each UE randomly from 1 to 10 and velocity of the mobile will vary from 1 to 10 km/h and 1 to 5 km/h for non-hotspot UE and hotspot UE respectively. Each UE has different UL and DL rates in the range of 0 to 1.5 Mbps for UL and 0 to 2 Mbps for DL.Direction of UE movement is completely random, in any direction, and the direction will be constant for minimum 5 seconds. After snapshot, the directionof UE may or may not change.

Table 1. Simulation Parameters

Parameter	Value
Macro cell radius	299m
Pico cell radius	40m
Carrier frequency	2.0GHZ
Bandwidth	10MHZ
Thermal Noise Density	-174dBm/HZ
Macro Base Station	1
Pico Base Station	2
UEs inside macro cell	50
UEs inside hotspot area	25
MBS Transmission power	46dBm
PBS Transmission power	30dBm
Velocity of UEs	1 to 10 km/h
Traffic demands	UL:0 to 1.5mbps DL:0 to 2mbps
Battery level	1 to 10 (Random)
Macro Path Loss Model	128.1+37.6log(R)dB(R[km])
Pico Path Loss Model	140.1+36.7log(R)dB(R[km])

The simulation scenario for the proposed system is

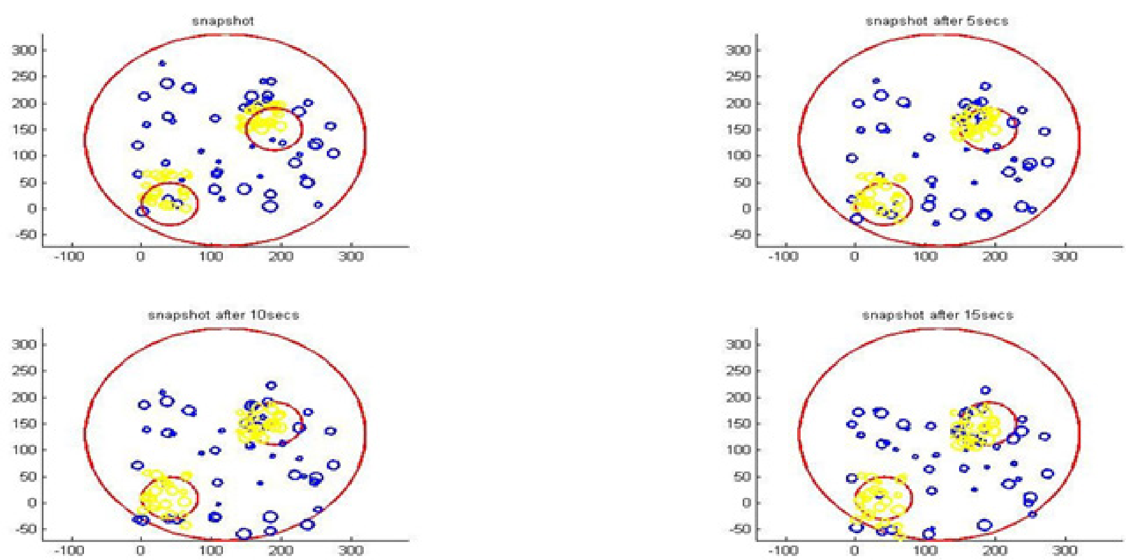

Figure 2. Simulation Scenario.

shown in Figure 2. The red colour denotes the cells and blue colour denotes the UE distribution. Macro cell is shown as big circle and pico cells are shown as small circles.Blue circle radius implies UEs battery level. PBS1 is placed near MBS and PBS2 is placed far from MBS to analyse the importance of PBS location in generating optimal bias value. UE are distributed randomly over the area and snapshots are taken for every 5 seconds. As illustrated in the Table 1, the simulation parameters are taken and evaluated for 15 seconds with four snapshots. Our proposed model is compared with fixed bias value method and max-Signal to Interference Noise Ratio (SINR) model without CRE technique.

5. Discussion and Result Analysis

In Figure 3 below, we depict the results of our analysis as to how the CRE technique helps to increase the utilization of pico cells. In max-SINR model UE will associate with BS which has larger signal strength. Since it does not consider any CRE technique, PBSs are underutilized with fewer UE. Compared to max-SINR model, fixed bias CRE will leads to increasein the number of UEs connected to PBS and maximize the utilization of pico cells.

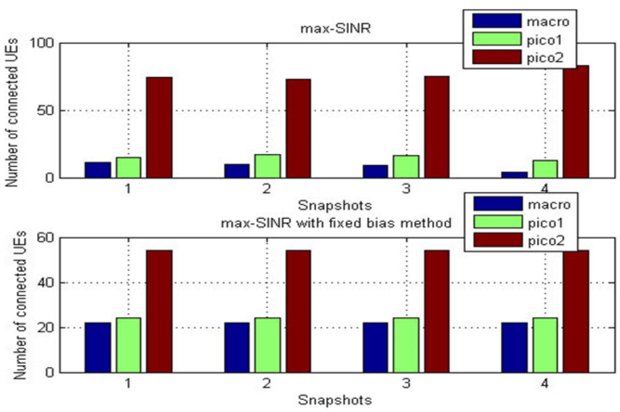

Figure 3. Comparision of IP-CREwith Resource Sharing known and Max-SINR.

Our analysis of the effectiveness of bias value without considering any outages is shown in Figure 4. When bias value increases, the number of UE connected to PBS also increases. For higher bias value, higher number of UE are connected to PBS with very low signal which leads to higher DL interference from MBS, with the best bias value varying in the range of 0 to 20. This experiment helps to set the membership functions of output bias value in our proposed intelligent system.

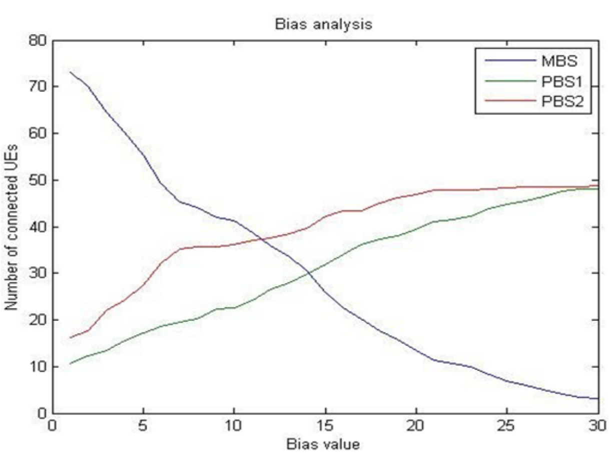

Figure 4. Bias analysis Graph.

We experimented (shown in Figure 5.) with various bias values and noted the average number of expansion region PUE. It is seen that the average number of expansion region PUE increases as bias value increases. Since PBS1 is placed near MBS, the average number of expansion region PUE is less for minimal bias values. The effectiveness of bias value on number of expansion region PUE depends on the location of PBS in MBS coverage area. We have to consider the location of PBS in MBS coverage area for getting an optimal bias value.

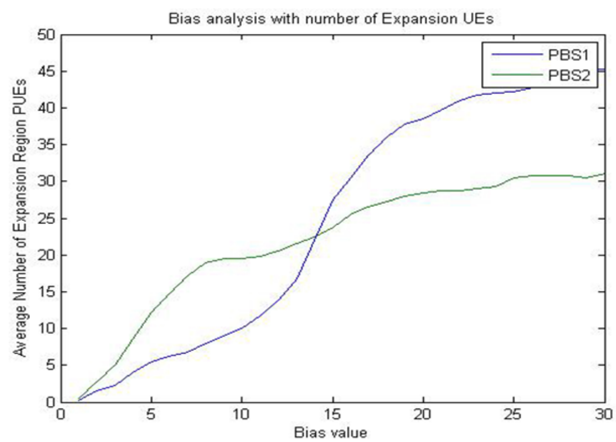

Figure 5. Expansion Region analysis graph.

Figure 6 depicts the IP-CRE versus the number of connected UE when RS is known. IP-CRE controls the number of connected UE according to RS between PBS and MBS.

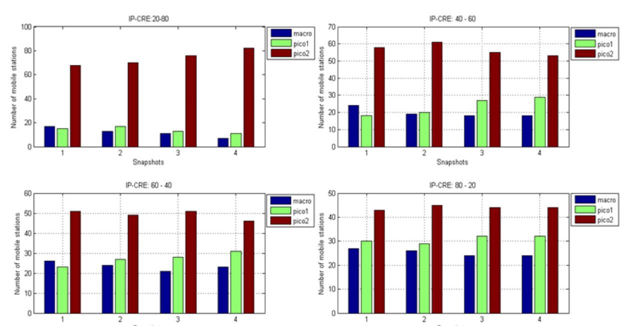

Figure 6. IP-CRE with various Resource Sharing Technique.

In Figure 7, the traditional fixed bias method is compared to IP-CRE with RS known and IP-CRE when RS is not known. Our proposed IP-CRE reduced the number of outages in almost all resource sharing possibilities between MBS and PBS. The number of outage UE is low when RS between MBS and PBS is known to UE. Hence the optimal bias value will also depend on the RS between MBS and PBS.

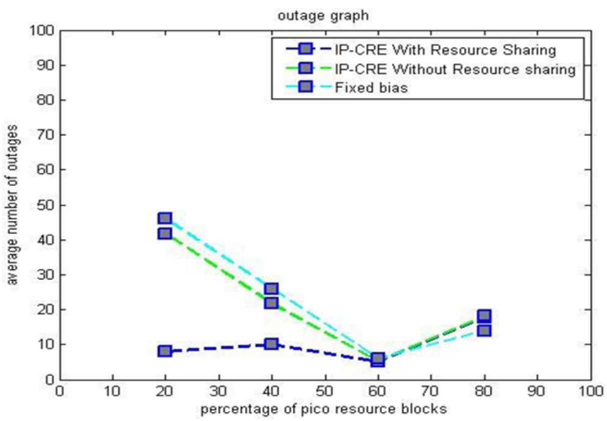

Figure 7. Outage Graph.

6. Conclusion

Our proposed solution of IP-CRE calculates the effective bias value for each mobile station independently, by using a fuzzy logic inference system. Our proposed solution takes multiple attributes like signal strength of pico and macro cells, speed and direction of mobile stations, battery level and traffic requirements as input parameters and an effective bias value was calculated for each mobile station. We analyzed the effectiveness of the bias value by varying the number of connected PUE in the expansion region. Our observations based on the simulation experiments demonstrate that the best bias value will be in the range of 0 to 20 and the optimal bias value also depends on the location of PBS in the MBS coverage area. Based on the results from our study, it is also observed that it is possible to reach the near optimal bias value even without knowing the distribution of UE. Our proposed solution can decrease the number of outage UE at almost all ratios of RS compared to fixed bias method. Our future work will be to explore and evaluate the interference with CRE caused by both MBS and PBS and to propose suitable mechanism to reduce the interference.

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