CELL SELECTION AND INTERFERENCE COORDINATION TECHNIQUES FOR HETEROGENEOUS WIRELESS NETWORKS

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ABSTRACT

CELL SELECTION AND INTERFERENCE COORDINATION TECHNIQUES FOR HETEROGENEOUS WIRELESS NETWORKS

The rapid growth of traffic demands during past years, has led to the immense deployment of heterogeneous wireless networks consisting large-scale macro cells overlaid with multiple tiers of small cells. This is conceived as the major capacity and performance enhancement coordinator by means of increasing the spectral efficiency per unit area.

However, heterogeneous networks implementation comprises new technical challenges related to interference issues and throughput deterioration. Advanced interference coordination techniques are introduced to handle these challenges. The usage of range expansion allows captivating more users and hence attaining performance improvement, however causes extra downlink interference. This becomes exquisite for higher bias values; hence the benefits convert into significant deterioration. To overcome these issues, range expansion should be jointly designed with inter-cell interference coordination.

The main objective of this thesis is to analyze the concept of heterogeneous network, the cell selection strategies including range expansion, interference coordination schemes and energy efficiency. The performance evaluations are obtained to different macro-pico base stations deployment scenarios for heterogeneous network by using various cell selection algorithms with and without interference coordination depending on frequency allocation schemes to figure out their impact on the system performance for different contours.

ÖZET

HETEROJEN KABLOSUZ AĞLAR İÇİN HÜCRE SEÇİMİ VE KARIŞIM ÖNLEME TEKNİKLERİ

Geçmiş yıllarda hızlı gelişen trafik talebi ayrışık kablosuz ağların artmasına sebep olmaktadır.Ayrışık kablosuz ağlar üstüne küçük hücreler yerleşmiş makro hücreler içermektedir. Alan başına spektral verimliliği artırarak büyük kapasite ve performans artışı sağlamaktadırlar.

Ancak ayrışık kablosuz ağların uygulanmasında girişim gibi sorunlarla karşılaşılmaktadır. Bu yöntem ile daha fazla kullanıcıya hizmet verilmesi sağlanmakta olup dolayısıyla daha iyi performansa ulaşılmaktadır. Hücreler arası oluşan bu girişimi çözmek için girişim koordinasyon teknikleri kullanılmaktadır ve böylece performans artışı gerçekleştirilmektedir.

Bu tezin amacı ayrışık kablosuz ağlar kavramını analiz etmek, hücre genişletme hücre seçim stratejisini, girişim koordinasyonu ve enerji verimliliği kavramlarını irdelemektir. Çeşitli hücre seçme algoritmaları kullanılarak ayrışık kablosuz ağlar için makro kapsama alanında farklı sayıda piko baz istasyonları yerleştirilerek performans sonuçları elde edilmiştir. Girişimin etkisini analiz etmek için hücre seçimi ile girişim koordinasyonu algoritmalarının başarım sonuçları da elde edilmiştir.

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LIST OF ABBREVIATIONS

3GPP	Third Generation Partnership Project
LTE	Long Tem Evolution
Het-Net	Heterogeneous Cellular Network
LPN	Low Power Node
BS	Base Station
RE	Range Expansion
EE	Energy Efficiency
4G	Fourth Generations
DL	Down Link
CA	Carrier Aggregation
CoMP	Coordinated multipoint
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operational Expenditure
CAPEX	Capital Expenditure
DSL	Digital Subscriber Line
RSRP	Reference Signal Received Power
SINR	Signal-to-Interference-Plus-Noise Power Ratio
PL	Path Loss
RSRQ	Reference Signal Received Quality
QoS	Quality of Service
RAT	Radio Access Technology
SE	Spectrum Efficiency
SINR	Signal-to-Interference plus Noise Ratio

WLAN	Wireless Local Area Network
FFR	Fractional Frequency Reuse
RNTP	Relative Narrowband Transmission Power
SFR	Soft Frequency Re-use
ABS	Almost Blank Sub-frame
RMPS	Reduced Macro power sub-frame
IPPS	Increased Pico power sub-frame
ICT	Information and Communication Technology
RF	Radio Frequency
RAN	Radio Access Network
GR	Green Radio
ECG	Energy Consumption Gain
MIMO	Multiple Input-Multiple Output

CHAPTER 1

INTRODUCTION

Due to the dramatic increase in demand for mobile broadband services all around the world, it is necessary to flourish service quality and coverage, increase data rates and capacity, enhance overall cell-site performance especially at cell-edges. The solution is to apply the denser topologies as heterogeneous networks, which has been added as one of the new limbs to meet IMT-Advanced assertions in 3GPP LTE Release 10. The heterogeneous network is being investigated in conjunction of cooperative strategies and interference coordination, so that the cell edge spectral efficiency is magnified.

Heterogeneous networks involve new base stations deployment with different types of transmission power, antenna patterns, backhaul connectivity. The low power pico nodes are installed within high power macro cell area to offload some traffic from the macro cell to pico cell and overcome the problem of coverage holes and enhance the user capacity at the cell edge area. However, the interference is still a prevalent aspect in case of such configurations. This interference becomes fatal when a technique of range expansion is applied to extend the low power node coverage to further increase the number of users being offloaded from the macro cell. Therefore, advanced interference coordination techniques are introduced to handle this interference scenario.

The thesis examines macro-pico heterogeneous networks and comprises the study of different deployment scenarios by considering various pico numbers, frequency allocation methods, cell selection algorithms, range expansion technique, interference, interference coordination techniques and the energy efficiency tradeoff with the system capacity. In addition, cell selection through interference coordination and energy efficiency based cell selection are the glorious sides of this work.

This thesis is organized in six chapters:

- Chapter 2 presents an overview of 3GPP long term evolution, the emergence of low power nodes to fulfill IMT-Advanced and other technical challenges.
- Chapter 3 discusses macro-pico heterogeneous network comprising concepts, spectrum allocation and cell selection methods. The impact of cell range

expansion on heterogeneous network is also studied for the case of orthogonal frequency allocation.

- Chapter 4 analyses the interference types and their sources in the heterogeneous networks. Cross-tier interference which arises due to the use of same spectrum by macro and pico users and coordination schemes of cross tier interference are also discussed. Moreover, effect of applying various cell selection methods through interference coordination algorithms including power allocation for macro and pico base stations is examined here.
- Chapter 5 describes power consumption model of heterogeneous network as well as different energy efficiency (EE) metrics and their trade off with the system capacity. In addition, a new technique called EE based cell selection for co-channel frequency allocation is proposed to increase the overall network energy efficiency in this chapter.
- Chapter 6 summarizes the concluding remarks. It also brings forward the future work to be done in order to continue the investigation of heterogeneous network.

CHAPTER 2

BACKGROUND OF HETEROGENEOUS NETWORK

In recent years, the elevation of wireless communications has experienced an excellent growth in mobile Internet traffic, which is expected to continue in the coming years. Whilst just a few decades ago mobile phones were commonly used for making calls and sending messages via SMS, the introduction of 3G, allowed the use of broadband data granting access to browse the internet. Later 4G, which assembles higher speeds, marked the development of mobile broadband and data oriented devices such as smart phones, tablets and other media hungry devices. A single smart phone or a single tablet can generate as much traffic as 35 or 121 basic-feature phones respectively. These devices are expanding rapidly and customers demand and expect to have global broadband access to online services, which have lead the acceleration of mobile data traffic growth. This traffic growth will turn to 11.2 exabytes (11.2×10^{18} bytes) per month by 2017, according to the report of Cisco VNI [1]. Not only connected people, but connected objects like mobile, machine-to-machine (M2M) connections will also devote to this growth.

Such expansion is referred to as the mobile data blast. This data blast becomes a tough challenge for mobile operators, since new ways are desired to get greater capacity to enhance the quality of service (QoS). As, 66% of voice and 90% of data traffics are generated indoors [2], polishing system performance implies boosting indoor coverage and capacity.

2.1. LTE Evolution

To answer the challenge of providing momentously faster wireless data transfer speeds, Long Term Evolution (LTE), arrived as a part of the Third Generation Partnership Project (3GPP) Release 8 standardization [3,4]. It is a broadband wireless access technology which is modeled to shelter the mobile Internet access via cell phones or handheld devices. As LTE offers significant performance improvements over former cellular communication standards, it is commonly referred as fourth generation (4G) technology. A workshop was held to work on the 3GPP LTE radio interface in 2004, where requirements and design targets comprised high data rate at the cell edge, low latency in accumulation to the normal capacity, peak data rates of 100 Mbps and spectrum elasticity.

In 2005, LTE design targets were sanctioned [5]. By the end of 2005, 3GPP resolved that LTE radio access should be based on orthogonal frequency-division multiplexing (OFDM) in downlink (DL) and discrete Fourier transform spread OFDM (DFTS-OFDM) in uplink (UL) and by the end of 2007, the LTE specifications were granted [6]. As time passed, the work has continued on with the addition of novel features in each release of the specification. The very first release of LTE specifications "LTE Release 8" was ready by the end of 2008. By the end of 2009, Release 9 was introduced with exceeding features. In March 2010, LTE Release 10 was introduced as a leading step in the evolution of LTE [7]. Support for carrier aggregation (CA), advanced MIMO (multiple-input multiple-output) techniques, coordinated multipoint transmission/Reception (CoMP), heterogeneous networks (Het-Nets) and relaying are the most prominent features which were included in this release. This release has been denoted as LTE-Advanced (LTE-A).

LTE releases have high data rate comparing with previous technologies along with the capability to meet future requirements and user expectations. Hence, most worldwide operators nowadays adopt LTE as its next generation wireless access systems to offer faster Internet access with lower latency and higher spectrum efficiency than previous 3G/3.5G wireless data communication technology [8]. Basically, LTE is an evolving technology, which is based on the GSM/EDGE and UMTS/HSPA network technologies, is able to increase the capacity and speed using different radio interface together with core network improvements [9]. LTE is now growing dynamically, with 13 million new subscriptions added in 2012 and will reach around 1.6 billion subscriptions in 2018 [10].

As LTE introduced a contemporary radio interface based on OFDM, it is capable to support bigger transmission bandwidths up to 20 MHz. Nonetheless, the peak LTE data rate of 300 Mbps is still remote way from the International Mobile Telecommunications Advanced (IMT-A) requirement of 1 Gbit/s for candidate Fourth Generation (4G) systems [11]. However, ongoing predictions for future systems point out enormous challenges far beyond what the ITU initially established for 4G. Driven by both the explosion of users' demands for mobile data along with new services and applications, and the need for an inclusive and wirelessly accessible cloud platform, the evolution of future mobile traffic is expected to blast. With these presages in mind, it becomes difficult to provide not only very high broadband capacity, but also efficient support for multicolor traffic types, yieldable and cost efficient deployments, energy efficient communications strategies, muscular systems against emergencies and parity between backward compatibility and future augments.

In general, the evident way to boost the capacity is to apply new spectrum to telecommunications and flourish spectral efficiency per link. However, radio spectrum has become rare merchandise and spectral efficiency per link is already approaching theoretical limits. An illustration shift in framework deployment is necessary to cost effectively increase the capacity of cellular wireless networks. In order to enhance network Capacity and accomplishing 4G requirements, researchers and mobile network operators need to enhance the current framework by adding new technologies and flourishing other ones. The new modulation schemes and coding techniques permit to reach theoretical bounds and in order to achieve that high required data rate more bandwidth is needed. The desired bandwidth in IMT Advanced is 40 MHz and 100 MHz is included in LTE Release 10 specifications [7], these bands are unlikely to be adjoining for each single operator.

Therefore, LTE-Advanced propounds the use of advanced technologies [12]. In the same manner, carrier aggregation (CA) allows the coexisting utilization of different frequency carriers, which efficiently boost the bandwidth that can be allocated to end-users. Besides, the enhancement of multi-antenna techniques, where using MIMO systems with up to 8x8 antenna arrays has gained indicative attention. CoMP transmission and reception, where multiple cells are able to coordinate their scheduling or transmission to serve users with adverse channel conditions, is also conceived to citable extinguish disruptions at the cell-edge. On the other hand, all these advanced technologies do not allow significant enhancements as they are reaching theoretical limits. These techniques may not always work well either, notably under low Signal-to-Interference Plus Noise Ratio (SINR) conditions, where received powers are inferior due to attenuation.

In spite of defeating these issues and adding a significant network performance leap, small cells such as pico and femto cells, seem to be one of the most viable and economic solutions [13].As installing more macro sites, is not a fascinating approach due to high Capital Expenditure(CAPEX) and Operational Expenditure (OPEX) costs that are related to such network upgrade.On the other hand, deploying Low Power Nodes (LPNs) in the areas that experience much higher demands due to the high density of users, like shopping malls or airports, is a more profitable solution. Femto-cell basically graphed for use in a home or an office and deployed by users, using the user's Internet connection, such as cable or Digital Subscriber Line (DSL) Internet services as a backhaul. Macro and pico cells are monitored by mobile network operators and utilize dedicated backhauls. Small cells are also acknowledged as a way of incrementally boosting coverage and capacity inside the initial deployment of macro cells, which is called Het-Net. A Het-Net can be expanded further with relay nodes or WiFi hotspots, which also makes it a multi-RAT network. Small cells create the convenience to off load mobile traffic and prinking small cells with Wi-Fi module provides even better traffic legislation.

Het-Net expounds deploying new base stations with different types of transmission power, antenna patterns, backhaul connectivity, etc to prosper spectral efficiency per unit area. In accordance with 3GPP, the macro cell layer will blend with LPNs, which are placed to offload some traffic from the macro cell. That helps to overcome the problem of coverage holes and enhance the spectral efficiency at the cell edge and eventually per unit area [14]. However, the interference is still an ascendant phenomenon in such frameworks. If LPNs are not deployed in a hotspot, very few UEs are likely to connect to them; this would limit the gain from traffic offloading. Besides, since cell selection criteria are typically downlink based, macro users would generate high interference in the LPNs. So a technique of range expansion with interference refutation schemes is a candidate option that operators might use to enlarge the LPNs coverage, to further increase the number of users being offloaded from the macro cell. This full framework will be discussed elaborately in Chapter-3.For the time being, here in this chapter only basic idea of Het-Nets is discussed including deployment scenario of various LPNs, their attracting sides and overall challenges.

2.2. Heterogeneous Networks

Till forthwith, wireless cellular networks were typically installed as homogeneous networks and the planning process was centered around macro base stations. In such a homogeneous network all cell sites have approximately the same characteristics, most significantly similar transmit power levels. The location of the cell sites is chosen with meticulous planning, in order to provide good coverage and to avoid interference as much as possible. However, such networks are not capable to meet the present-days huge data traffic capacity demand, as the spectral efficiency per link has practically reached its theoretical limit [7]. Increasing density of the macro layer may offer some gain, but the benefits are limited by cost and interference.

2.2.1. The Emergence of the LPNs

By considering above issues, LTE-A offers Het-Nets, where low power nodes like picocells, femtocells and relays can be overlaid with conventional high power macro node in order to fetch the network closer to end-users, shown in Figure-2.1. Such low power nodes can be either operator deployed or user deployed and may coincide in the same geographic area, potentially sharing the same spectrum. In that way, radio link quality can be enhanced due to the reduced distance between transmitter and receiver. In addition, due to the conveniences of spectrum reuse efficiency, the network operators are also captivated by financial benefits because small cells can reduce both capital (hardware) and operating (electricity, site lease and backhaul) expenditures. As a result, Het-Nets are expected to be one of the leading execution enhancement enablers of LTE-Advanced [12]

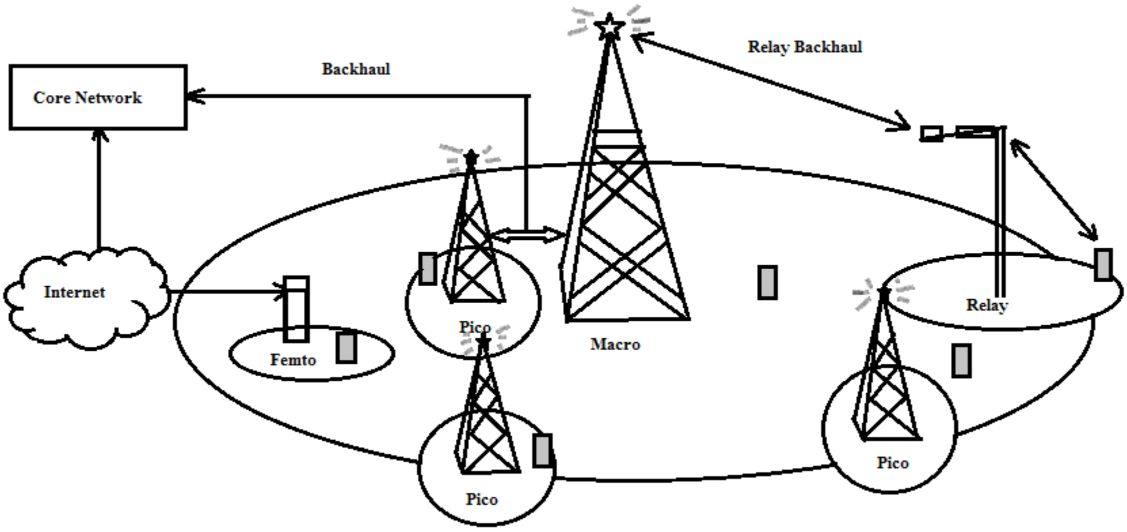

Figure 2.1. Heterogeneous network: mix of macro, pico, femto and relay base stations

Macrocells: Macrocellular networks consist of traditional operator installed base stations (BSs), equipping open public access and a wide area coverage typically on the order of few kilometers. In LTE, they are also called enhanced Node Base stations (eNBs). These eNBs can handle thousands of users simultaneously. Due to high installation costs like cabinet, feeders, large antennas, 30-50 m towers etc, macro cells are very costly. The cells have three sectors and construct the heart of the cellular network. Transmitting power levels of macro cell are very high, 5 to 40W (37 to 46 dBm) [15].

Microcells: A smaller coverage area than macro cells is granted for microcells. They are usually deployed to enhance coverage in urban areas. Micro cell can handle hundreds of users with lower installation costs than macro cells. It is easy to find them on the roofs of buildings. Micro cells can have three sectors as well, except the tower structure. Transmitting power level is .01 to 2W [15].

Picocells: Pico-cells are low-power, operator-installed cells with the same backhaul and access aspects as macro cells. They are usually installed in a centralized way by serving few tens of users within a radio range of 300m or less and have a typical transmit power range from 23dBm to 37dBm. Pico-cells are mainly used for capacity and outdoor or indoor coverage infill, i.e. in environment with poor macro penetration (office buildings) [16].

Femtocells: Femto cells are low-cost, low-power, user deployed access points used for off loading data traffic using consumers' broadband connection like DSL, cable or fiber. They are introduced for use with 4G systems (LTE and WiMAX), also known as home BSs or home eNBs and can serve a dozen of active users in homes or enterprises with power levels less than 20 dBm. A Femto cell can generate very high downlink (DL) and uplink (UL) data rates and thus provides multi-Mbps per user. That helps to attain mobile multimedia, anywhere, anytime, with global mobility support, integrated wireless solution and customized personal service [16].

Relays: These are operator-deployed access points that route data from the macro BS to end-users and vice versa. They are seated so as to increase signal strength and to enhance reception in poor coverage areas and dead spots in the existing networks like cell edges, tunnels etc.

LPNs Deployment:

LPNs deployment is a big challenge in Het-Nets as there are many aspects need to be considered.

- **Demand:** Traffic demand like volumes, traffic location, target data rates are the main focus of any Het-Net.

- **Supply:** Macro cell coverage, site availability, backhaul transmission, spectrum and integration with the existing macro network should be taken into account in case of LPNs deployment.

- **Open or Closed Access:** Open access means LPNs are open for all subscribers to access. Open access should be privileged for public systems deployed by operators. Besides, closed access indicates that LPNs belong to a Closed Subscriber Group (CSG) that means access is only permissible for users in CSG. Closed access is used in user deployed cases like individual and enterprises.

- **Indoor or Outdoor Deployment:** When traffic is concentrated to a specific indoor location such as shopping mall, deploying indoor LPNs is more preferable. Outdoor LPNs deployment which also covers indoor areas is desirable in cases, where local traffic hotspots tent a wide area including several buildings or the macro cells in the existing networks are too rare to meet indoor service requirement.

- **Type of LPNs:** There are several types of LPNs such as conventional pico nodes, relay nodes etc. P ico base stations are suitable for networks with high-latency and low-capacity backhaul. Deploying relay nodes is a suitable option for networks without wire backhaul.

- **Frequency Reuse**: The Het-Nets can be seen as composed of two layers: macro cell layer and pico cell layer. The two layers can use different frequency band or share the same band. Reusing the frequency band of the macro cell layer for the pico cell layer is of course spectrum efficient. When spectrum is limited or capacity is the driver, frequency should be reused. More detail discussions are given in spectrum allocation.

2.2.2. Importance of Heterogeneous Networks

The research association has yielded a considerable body of knowledge on various cellular communication techniques, ranging from wide area to pico cells in the past. Though, no strategy to clout the capabilities of such solutions within a unified framework has been exhibited so far. Imposing a hierarchical cellular network, Het-Net aims to boost the network performance by coordinating the resource allocation and service delivery using nodes with different transmission capabilities within a given cell. Moreover, it can provide a cost effective rollout plan with much reduced financial risk to operators.

User anticipations for mobile broadband are on the rise as people rely more and more on mobile applications, video content, cloud-based services and staying connected anywhere, anytime. People have come to expect a compatible, high-quality and seamless mobile broadband expertise wherever they are.Hetrogeneous network ensures a seamless user experience at maximum efficiency across outdoor and indoor environments.

In conventional cellular networks, cell edge users still receive much weaker signal power as compared to those near macro base stations due to large propagation attenuation. Het-Net i mprovess cell edge user performance by installing a variety of low-power nodes along with traditional high power macro node which confirms overlay coverage for cell edge users.

Furthermore, these low-power nodes can also be deployed in hotspot areas, e.g., office buildings, to offload traffic from macro cells and can therefore increase spectral efficiency per unit area by allowing denser spatial reuse. That means spectral efficiency is boosted per unit area via spatial reuse in heterogeneous network.

In Het-Net, different Radio Access Technologies (RATs) are designed for different purposes, so different types of access nodes are available which ensures a diversified coverage, with handoff ability between network elements.

2.2.3. Technical Challenges

Self-Organization, Backhauling, Mobility management and Interference are the major key technical challenges offered during implementing Het-Nets [14].

A. Self-organization

As some cells like femto cells will be user-deployed beyond operator inspection, their proper operation highly confides on their self-organizing features [4]. The self-organizing capability of Het-Nets can be generally classified into three processes:

- *Self-configuration*: Here before entering into the working state, the newly deployed cell is automatically composed by downloaded software.

- *Self-healing*: Where cells can automatically accomplish failure salvation or execute indemnification mechanisms whenever failures occur.

- *Self-optimization*: Cells continually monitor the network status and optimize their settings to enhance coverage and decline interference.The deployment of self-organizing Het-Nets is a complicated task due to the different types of coexisting cells and the rising number of network parameters that need to be weighed. The random, uneven and time-varying nature of user arrivals along with their resulting traffic load also amplifies the difficulties associated with deploying a completely self-organized Het-Net.

B. Backhauling

Due to the complex topology of the various types of coexisting cells, the backhaul network design will be a leading issue for Het-Net. The deployment of pico cells will desire access to utility infrastructure with power supply and wired and wireless network backhauling, which may be potentially costly. Femto cells, which have relatively lower backhauling costs, may face troubles in keeping Quality of Service (QoS) as backhauls rely on consumers' broadband connections. Therefore, operators need to plan Het-Net backhaul cordially to identify the most cost effective and QoS guaranteed solution. A mixture of both wireless and wired backhaul technologies can provide such a solution, in which some cells may have, dedicated interfaces to the core network, some other cells may form a cluster to aggregate and forward the traffic to the core and other cells may rely on relays as a substitute interface.

C. Mobility Management, Handover

Handovers are essential to ensure a seamless uniform service when users move in or out of the cell coverage. In addition, handovers are essential for traffic load balancing, by shifting users at the border of contiguous or overlapping cells from the higher congested cells to the lower congested ones. Even, this comes at the expenditure of system overhead, which is likely to be effective in Het-Nets due to the large number of small cells and the different types of backhaul links available for each type of cell. Moreover, the probability of handover fizzle enhances the probability of user outage.

D. Interference

Even though the deployment of low power access points can improve achievable wireless data rates, these benefits are accompanied by several technical and economic challenges. The most prominent technical challenge is co- and cross-tier interference. Interference mitigation in Het-Nets has been charmed animus in both academia and industry. In a Long Term Evolution (LTE)-Advanced system, interference management is referred as enhanced Inter-cell Interference Coordination (eICIC).Sources, types and interference mitigation techniques are described in details in the chapter-4.

Heterogeneous networks are expected to be an integral component of future LTE network deployments and Ericsson has projected that by 2017 each urban macro base station will be complemented by an average of 3 small cells [3]. In practice, a small cell unit can look like a WiFi access point; however, it also includes all the core network elements.

CHAPTER 3

CELL SELECTION FOR HETEROGENEOUS NETWORKS

As it was discussed in the previous Chapter, the typical scenario of a Het-Net is that the LPNs are blended with conventional well planned macro cells with each other, in terms of increased data rates and cell coverage. Usually the low power nodes are placed in an unplanned manner [17]**.** Among the low power nodes, the introduction of pico cells play significant behavior in order to accommodate efficiently high volume traffic in local areas, i.e., hotspots, and exaggerate the overall system capacity. Though, a downlink/uplink disequilibrium problem occurs. The downlink coverage of the pico cell is much smaller than that of the macro cells due to a difference in the transmission power. On the other hand, as the transmitter is the set of UEs, this disparity in transmission power does not influence the coverage in the uplink. Therefore, the optimum cell in the downlink is different than that in the uplink. The cell range extension (CRE) which was proposed to increase the gain of pico can also perform effective role to compensate for the downlink/uplink imbalance.

In addition, to fully exploit the possible gains through heterogeneous network deployments, it is important to consider the differences in base station types and change the traditional single-layer homogeneous networks approach to comprise these differences. Network planning in Het-Nets differ from traditional network planning in several aspects.

After considering all above facts, this chapter examines overall macro-pico heterogeneous network scenario concentrating on cell selection schemes.

3.1. Heterogeneous Network Deployment

The deployment of heterogeneous networks characterized by a combination of macro cell and small pico cells is considered by many to be a key solution to the expected growth in wireless broadband traffic which is shown in Figure 3.1. This deployment brought in new scenarios in terms of cell selection, interference cancellation, and load management so on. To obtain maximum benefit out of the heterogeneous deployment in terms of capacity and coverage it is necessary to optimize these factors by making important choices:

1. Spectrum Allocation: Should macro and pico cells share the same spectrum (co-channel) or not (frequency re-use)?
2. Cell Selection Methods (Reference Signal Received Power/ Minimum Path Loss-based / Cell Range Extension)
3. How many pico cells should be deployed in each macro cell?

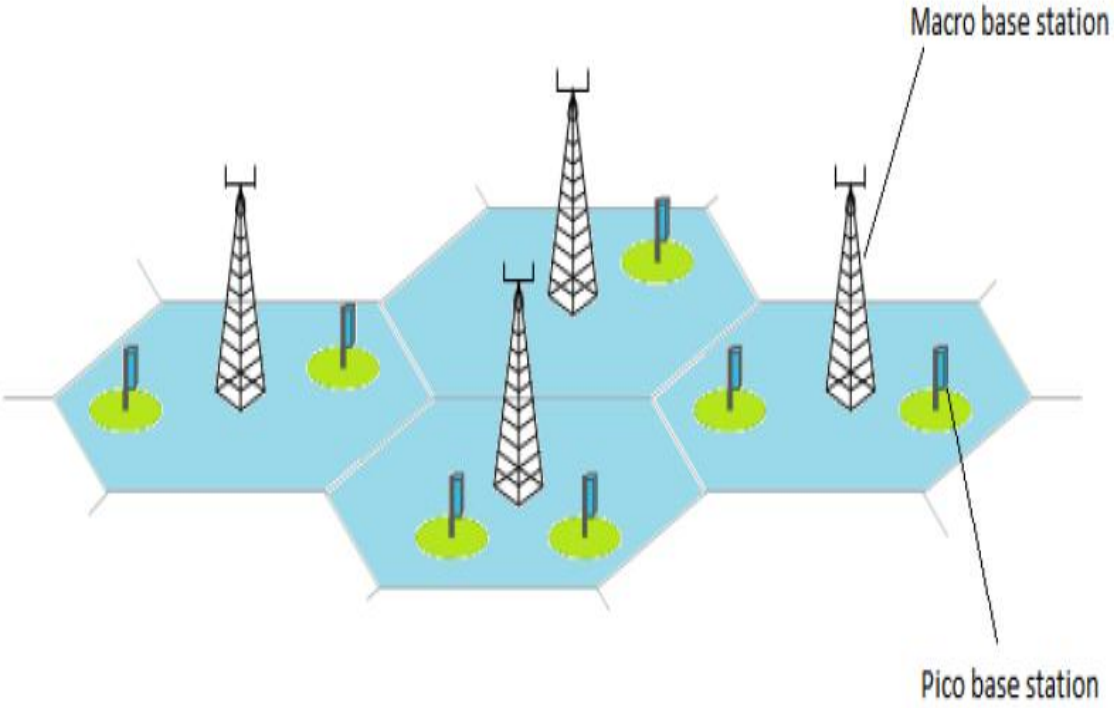

Figure 3.1. Heterogeneous network using pico-eNBs over macro cell

3.1.1. Spectrum Allocation

Spectrum allocation among macro cells and small pico cells is an eventual issue to Het-Nets. The following three approaches can be explored from the aspects of the capacity and coverage:

- Orthogonal frequency allocation

In Orthogonal frequency allocation, resources between macro and pico cells are appointed in a way so that they are not overlapped to each other. Moreover, Macro cell is designated to a part of the whole frequency resource and pico cell can use the remaining part. As, half of the whole bandwidth can be used for both macro cell and pico cell in this process, it has the worst cell group average throughput. Though, cell edge throughput is better in orthogonal frequency allocation than the frequency overlap case because of zero inter-cell interference between macro cells and local cells [18]. Simulations of this chapter have been done based on Orthogonal frequency allocation.

- Overlapped frequency allocation

In this process, partial overlapping of frequency resources between macro cell and pico cell can be observed. For example, pico cell is assigned to a part of the whole frequency resource, while the macro interpenetrates the whole frequency resource and vice versa. This type of assignment can reach a best cell group average throughput due to the friendly resource allocation of pico-cell, but the cell edge throughput is collapsed obviously over co-channel [18].

- Co-channel allocation

Entire frequency band of the network will be equally shared by macro cell and pico cell. It is a good parity between the cell group average throughput and cell edge throughput since both macro cell and pico cells can make full use of the whole bandwidth. Though, additional interference management needs to take into account in co-channel deployment.

If spectrum is sparse and capacity is the pilot, pico cells are likely to use the same spectrum as the macro cell (co-channel allocation). Co-channel spectrum allocation has the potential to grant higher system and user throughput than the separate spectrum assignments. Some fine tuning of range expansion and eICIC algorithms are required [19].

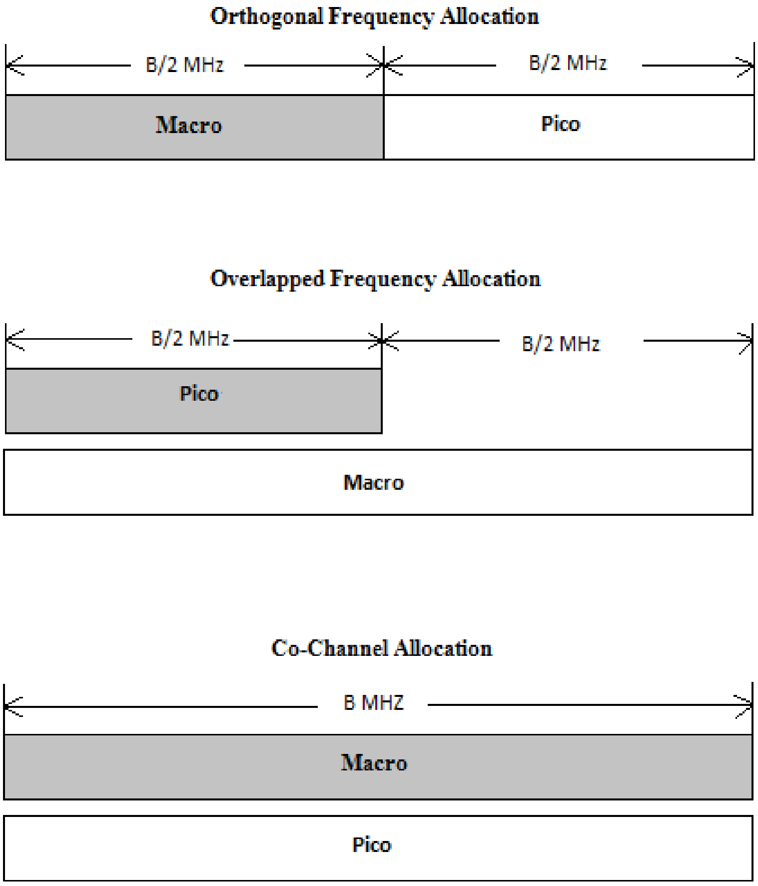

Figure 3.2. Different spectrum allocations: a) Orthogonal b) Overlapped c) Co-channel frequency allocation

3.1.2. Cell Selection Algorithms

Cell selection is the way of determining the best cell that brings service to the UEs. In a Het-net scenario, optimizing this process is an instant step towards balancing the system load and improving the capacity of the Network [20]. In traditional single-layer networks, cell selection is based on the highest reference signal received power (RSRP) measured at UE. While this gives the optimum selection methodology for these networks, it does not always apply to the HetNets where base stations have several transmit powers. Macro cell and picocell base stations, namely MeNBs and pico-eNBs, differ by almost 16 dB in their downlink transmit power levels [17]. If the cell selection is based on RSRP only, UEs are more likely to connect to the MeNBs even when the path loss conditions between the pico-eNB and the UE are better.

Some conventional cell selection techniques such as RSRP, Path Loss (PL) and Cell Range Extension (CRE) are the main focus in this sub-section.

Capacity for a fading channel [3] can be expressed,

$$\mathrm{C}_{u,k} = \mathrm{B}_u \ \mathbb{E}\left[log_2\left(1 + SNR_{u,k}\right)\right] \qquad \forall u, \forall k \tag{3.1}$$

where, $\mathrm{C}_{u,k}$ is the capacity of user k when it is connected to base station u , $SNR_{u,k}$ is the ratio of the signal power to the noise power,called Signal-to- Noise Ratio:

$$SNR_{u,k} = \frac{P^r_{u,k}}{P_N} \qquad \forall u, \forall k \tag{3.2}$$

where, $P_N = N_0 B_u$, N_0 is the noise power spectral density and B_u is the channel bandwidth. Since, there are 1 macro BS and (U-1) pico base stations in the considerations of this chapter, B_u can be expressed $\frac{B}{2}$ for macro and $\frac{B}{2} . \frac{1}{U-1}$ for pico base station. U is the total number of base stations in the network.

$P^r_{u,k}$ is the received power of user k from base station u including path loss, $PL_{u,k}$; shadow fading, $L^f_{u,k}$ and the channel fading coefficient, $h_{u,k}$.It can be defined as:

$$P^r_{u,k} = \frac{P^t_u}{PL_{u,k} . L^f_{u,k}} \ |h_{u,k}|^2 \qquad \forall u, \forall k \tag{3.3}$$

where, $h_{u,k}$ is modeled as $\mathcal{CN}(0,1)$ and P^t_u is the transmitted power from uth base stations.

Performances of different cell types and their selection methods are obtained in terms of capacity, following Orthogonal frequency allocation shown in Figure 3.2(a).

Reference Signal Received Power (RSRP)

Reference signal received power (RSRP), is prescribed as the linear average over the power contributions (in [W]) of the resource elements that convey cell-specific reference signals within the considered assessment frequency bandwidth [6]. RSRP based cell selection confirms good channel conditions in downlink [19].

The cell association is typically decided by the RSRP. In this technique, the user 'k' is always connected to the base station '$u*$' with the maximum downlink received power.

$$u^* = \arg\max_u \; RSRP_{u,k} \qquad \forall k \tag{3.4}$$

where, $RSRP_{u,k}$ is,

$$RSRP_{u,k}(dB) = P_u^t(dB) - PL_{u,k}(dB) - L_{u,k}^f(dB) \tag{3.5}$$

Minimum Path Loss (PL)

This is also based on RSRP but compensates for the base station transmits power differences on the reference symbols and therefore is more suited for the uplink [19]. Here user 'k' selects the base station 'u^*' with the minimum path loss

$$u^* = arg\,\underset{u}{min}\,PL_{u,k} \qquad \forall k \tag{3.6}$$

Different pathloss models are used for macro-UE and pico-UE links to reflect the differences in their propagation environment in the form of simplified model.

Biased RSRP

In Heterogeneous Network, there are several types of base stations that have individual transmission powers including several powers of Cell specific Reference Signal (CRS). This scenario is not different in case of macro-pico deployment. Therefore, a large transmit power disparity between macro and pico nodes is a common issue. Hence, RSRP approach for cell selection would be unfair to the low power pico nodes. The received signal power from pico node will be much less than that from macro node, hence, the dominant portion of users will choose macro node as their serving node. Therefore, pico nodes will be underutilized, and cell splitting gain will be reduced and will not be optimal in terms of downlink capacity.

As a solution of above issue, cell selection could be done by applying a cell-specific offset to the received power measurements used in typical cell selection method, called cell range extension method. This offset would somehow compensate for the transmitting power differences between the macro-eNBs and pico-eNBs; it would also extend the coverage area of the Pico-eNB, or in other words extend the area where the Pico-eNB is selected. This area is called "Range Extension" and is illustrated in Figure 3.3.

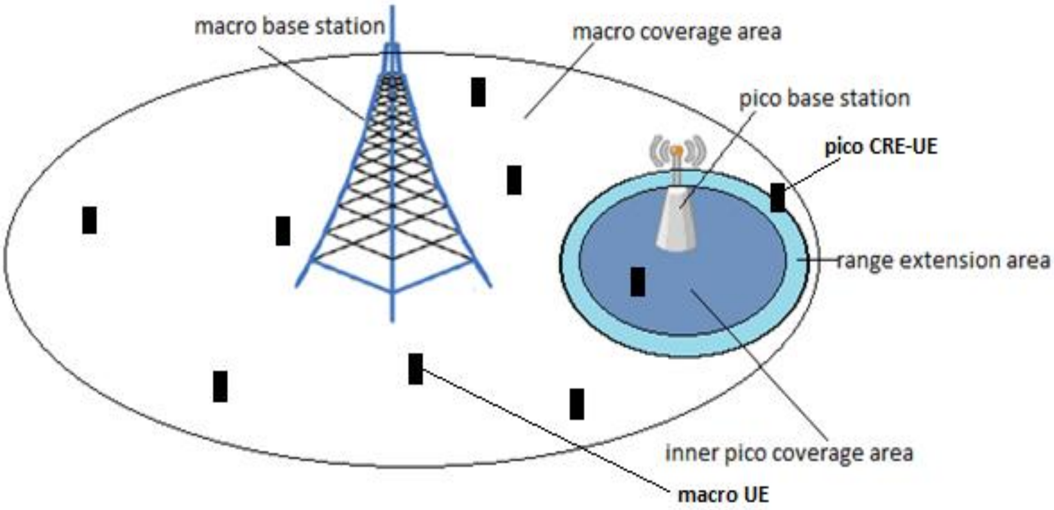

Figure 3.3. Range extension area illustration

In this strategy, the user 'k' will select its serving node 'u^*' using biased RSRP:

$$u^* = \arg\max_u RSRP_{u,k} + BIAS_u \qquad \forall k \tag{3.7}$$

where, $BIAS_u$ is the predefined biased value for node u ,which is zero for macro node and is positive (typically 5-10dB) for pico node. Hence, the bias value is used to improve the capacity of pico.

Although the cell range extension can allow more pico nodes to be chosen as the serving node, it will generate a severe interference situation for those pico users in cell expanded area, in which the downlink interference from neighboring macro cell will be even larger than the signal from the serving pico cell [18]. This interference issues will be discussed in the next chapter.

3.2. Performance Evaluations

To evaluate the impact of cell selection method and pico node density on Het-Net performance, two different scenarios are considered in the simulations. Scenario-1: one pico node over a macro cell (Figure-3.4), scenario-2: multiple pico nodes over a macro cell (Figure-3.11), both focuse only on the downlink operation. Moreover, Association ratio and average capacity are the two key performance indicators:

- Association Ratio: It is defined as the percentage of users served by a definite node.
- Average Capacity: It is the average of the total user capacity in the simulation area.

Macro-to-UE pathloss model,[35]

$$\mathrm{PL}_{u,k} = 128.1 + 37.6 \log_{10}(d_{u,k}[km]) \tag{3.8}$$

Pico-to-UE pathloss model,[35]

$$PL_{u,k} = 140.7 + 36.7 \log_{10}\left(d_{u,k}[km]\right) \tag{3.9}$$

where, ‘$d_{u,k}$’ is the distance between base station ‘u’and user ‘k’ .

Table 3.1. Simulation parameters for different cell selection methods

Parameters	**Setting**
Bandwidth	10MHz
Shadow fading	Log-normal distribution with variance 8dB for macro to UE and 10dB for pico to UE
Macro transmit power	46dBm
Pico transmit power	30dBm
User density per macro area	500
Noise power spectral density,$\mathbf{N_0}$	-174dBm/Hz

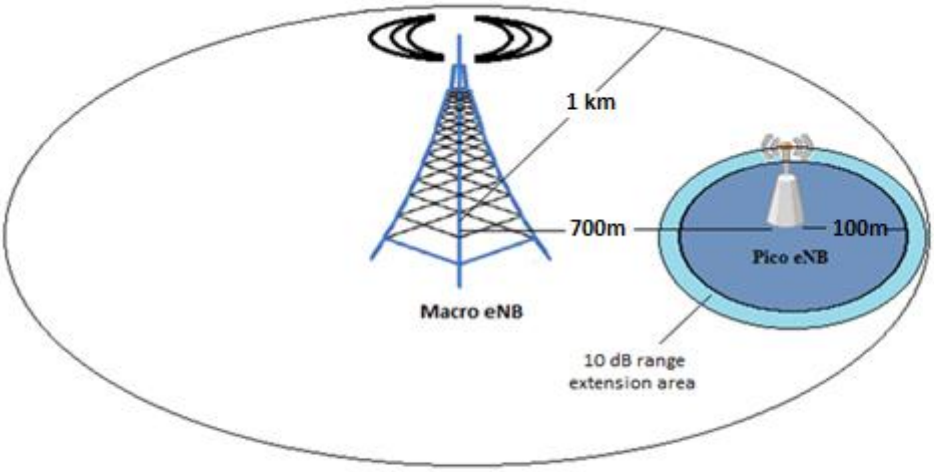

Figure 3.4. Scenario 1: One pico node over a macro cell area

Scenario-1

Association ratio and average capacity of users for different cells based on RSRP cell selection are shown in Figure 3.5 and 3.6 respectively . It can be seen from Figure 3.6 that the average capacity of macro-pico Het-Net is higher instead of macro only situation.

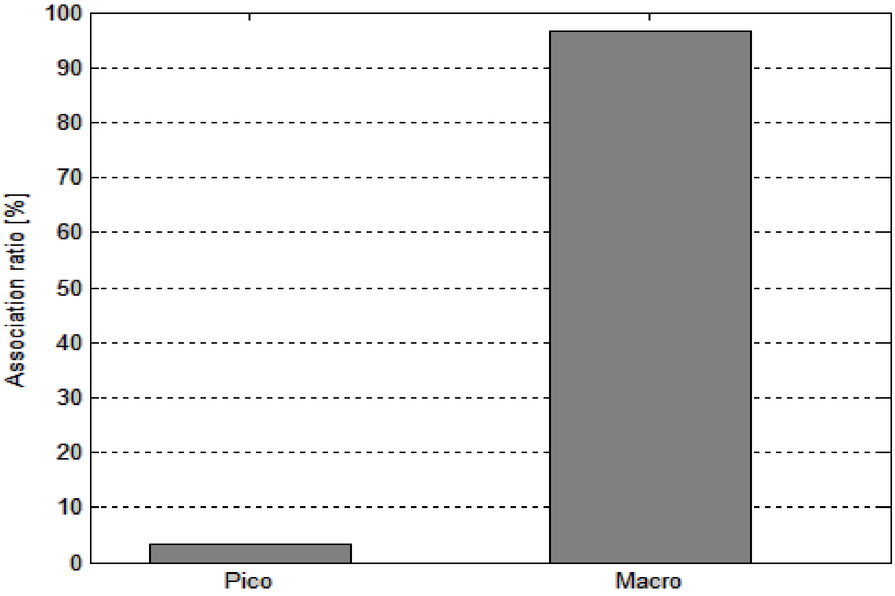

Figure 3.5. Association ratio of pico and macro node under RSRP based cell selection

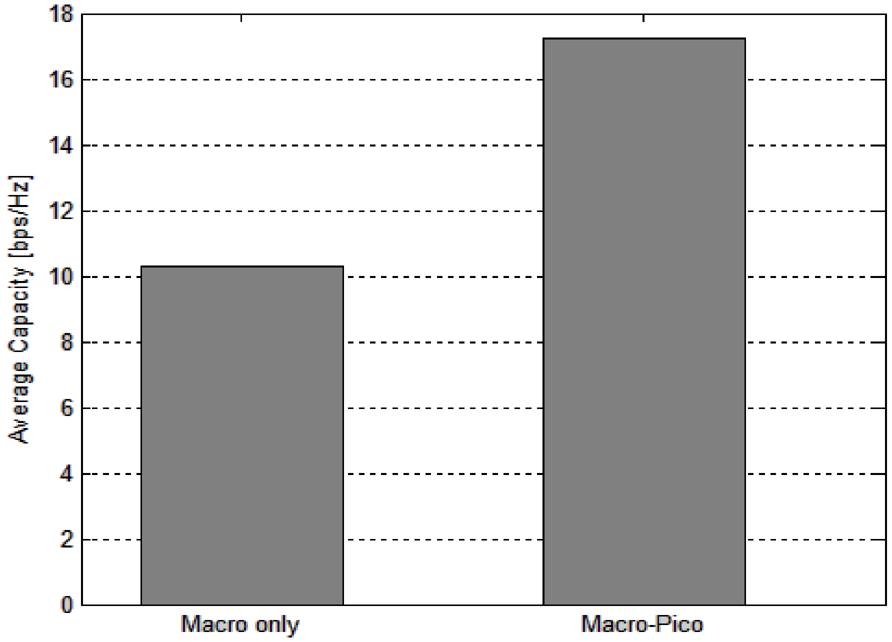

Figure 3.6. Average capacity for macro only and combined macro-pico situations

It is clear from Figure 3.7 and 3.8 that the different cell selection methods have different effects on association ratio of pico node and average capacity. RSRP with 10dB offset outperforms others in both cases.

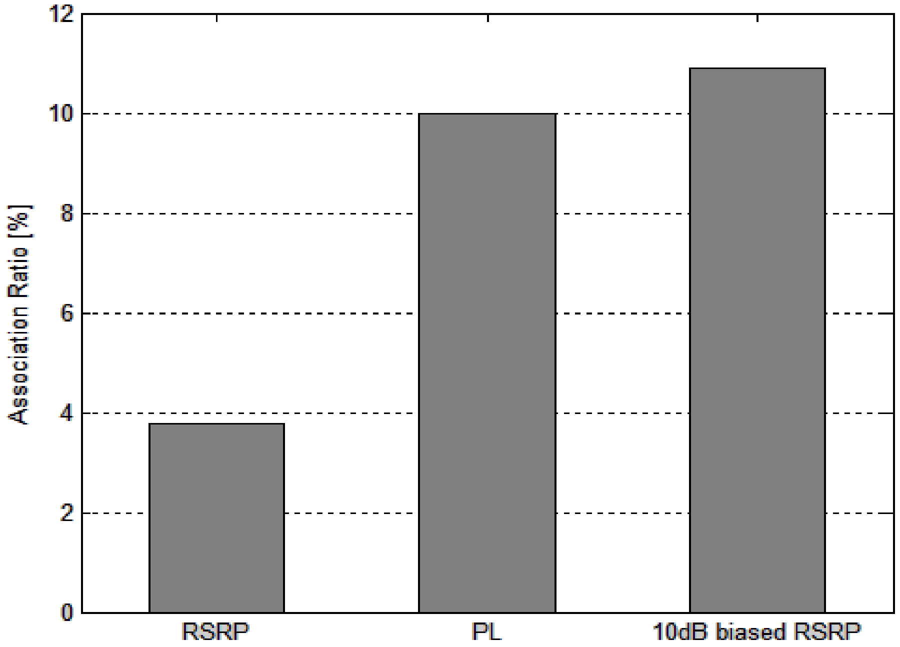

Figure 3.7. Association ratio of pico node for different cell selection methods

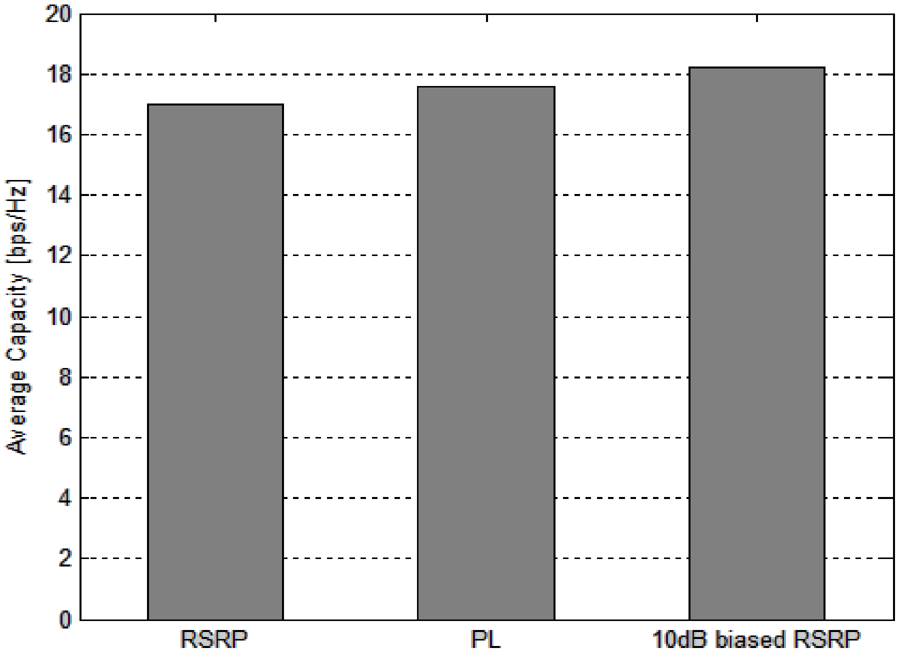

Figure 3.8. Average capacity for different cell selection methods

The larger the bias value is, the more users are offloaded from macro node to pico node. Moreover, a s the bias value continues to increase average capacity of users also increases. This overall scenario reflects on the Figure 3.9 and 3.10 below, where comparison among different bias values associated RSRP cell selection method is shown.

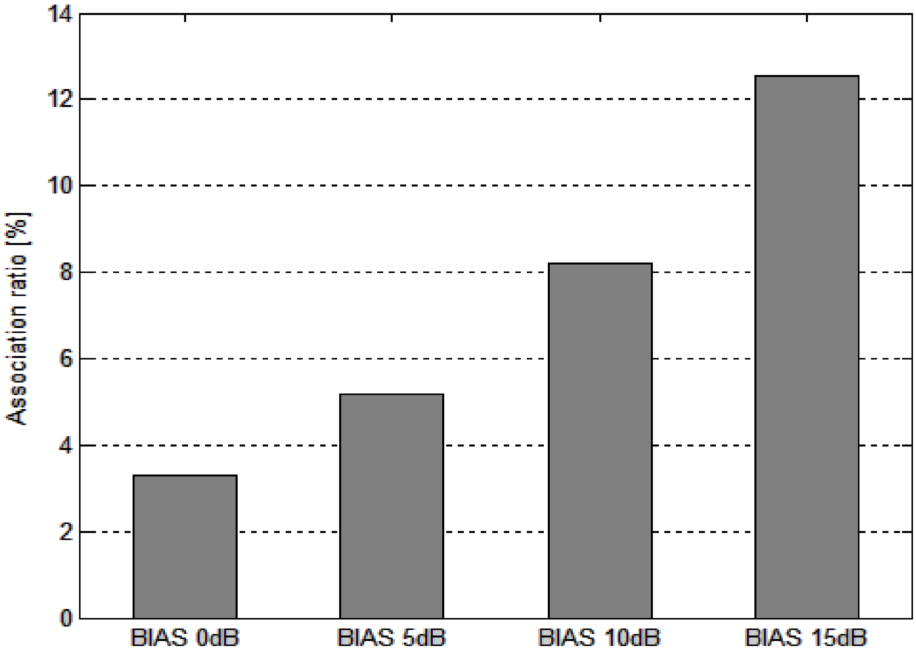

Figure 3.9. Association ratio of pico node for different BIAS values

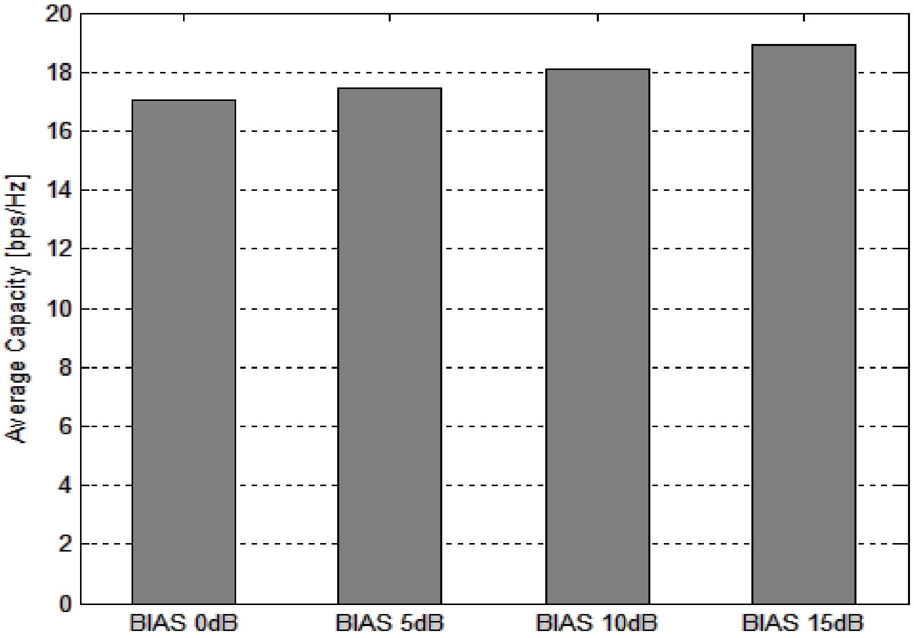

Figure 3.10. Average capacity for different BIAS values

Scenario-2

Association ratio and user capacity of the network, are not only dependent on the cell selection criteria but also on the number of pico deployed in macro coverage area. To evaluate this impact, 8 pico nodes are placed at different positions in macro cell area.The association ratio and average capacity under different pico numbers are shown in Figure 3.12 to 3.17, where RSRP,PL and 10dB biased RSRP are used respectively as cell selection methods.

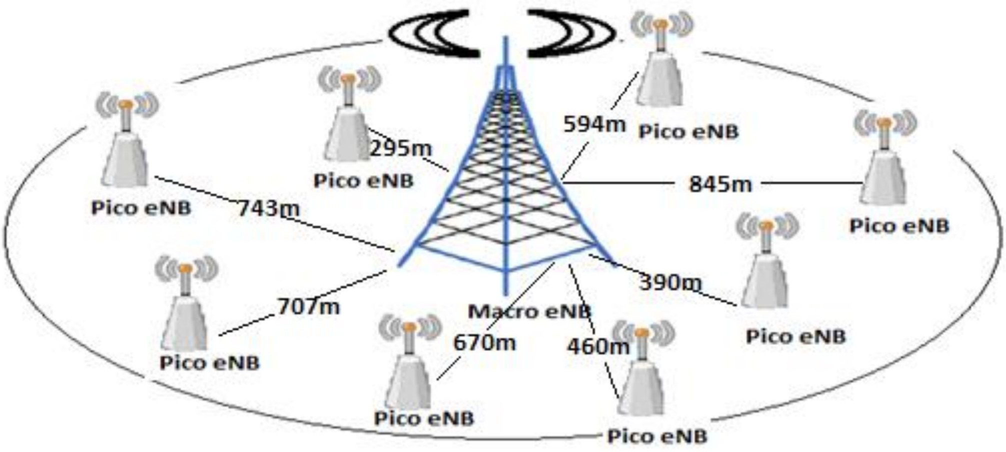

Figure 3.11. Scenario 2: 8-pico nodes at different positions in macro cell area

It can be seen that, as the number of pico increase per macro cell area, association ratio and average user capacity also increase.This mainly comes from moving more UEs closer to the pico nodes when increasing the pico density.

Since, there is a tradeoff between the system capacity and energy efficiency when deploying pico nodes over macro coverage area, a Het-Net does not allow as more pico deployment as requires in the system. A high number of lightly loaded small pico nodes increase the network power consumptions as well as overall system capacity, which will be discussed precisely in Chapter 5 .

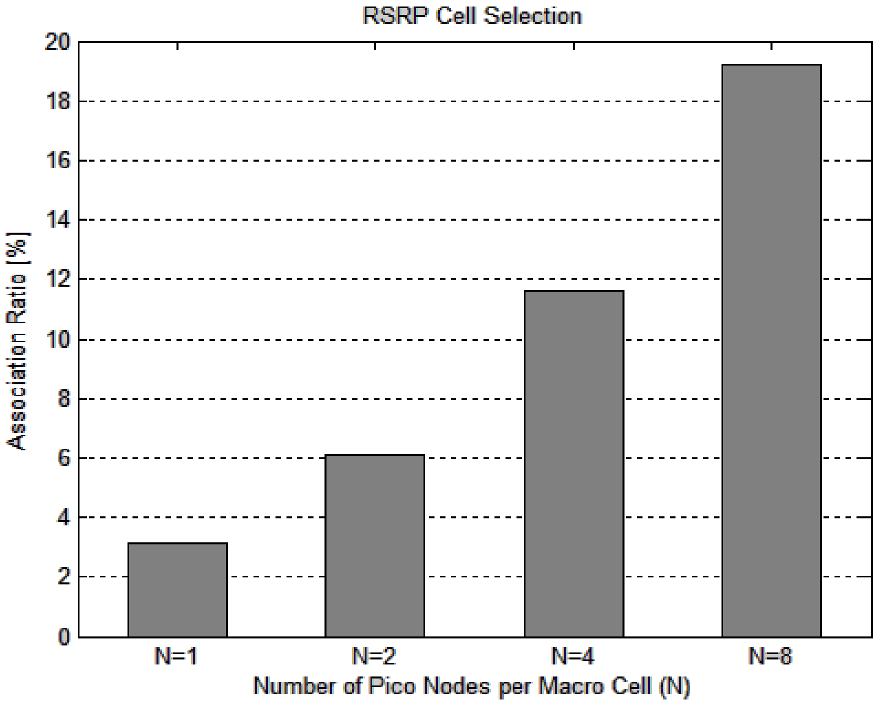

Figure 3.12. Association ratio of pico node under different pico numbers for RSRP based cell selection method

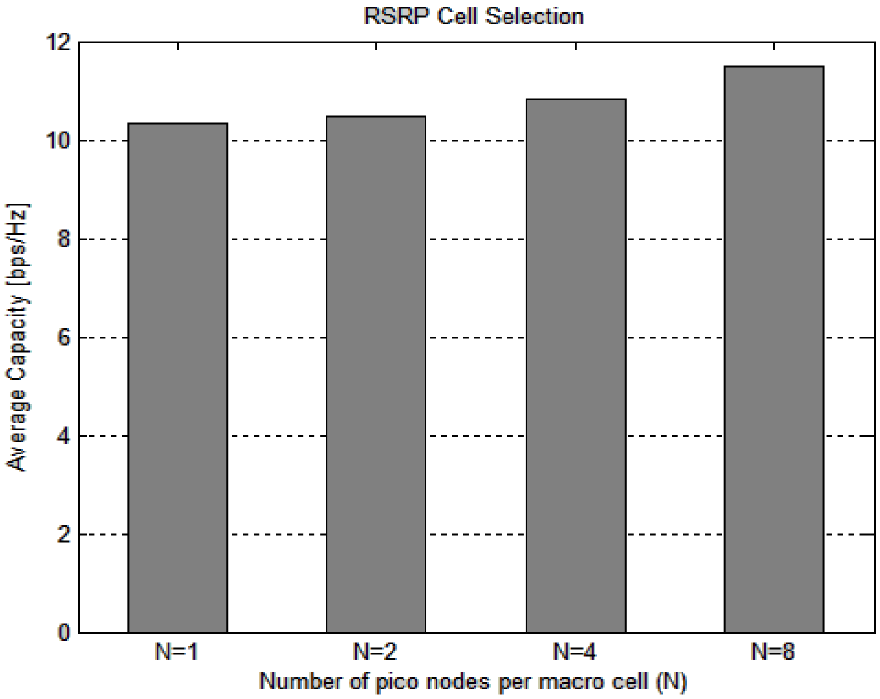

Figure 3.13. Average capacity under different pico numbers for RSRP based cell selection method

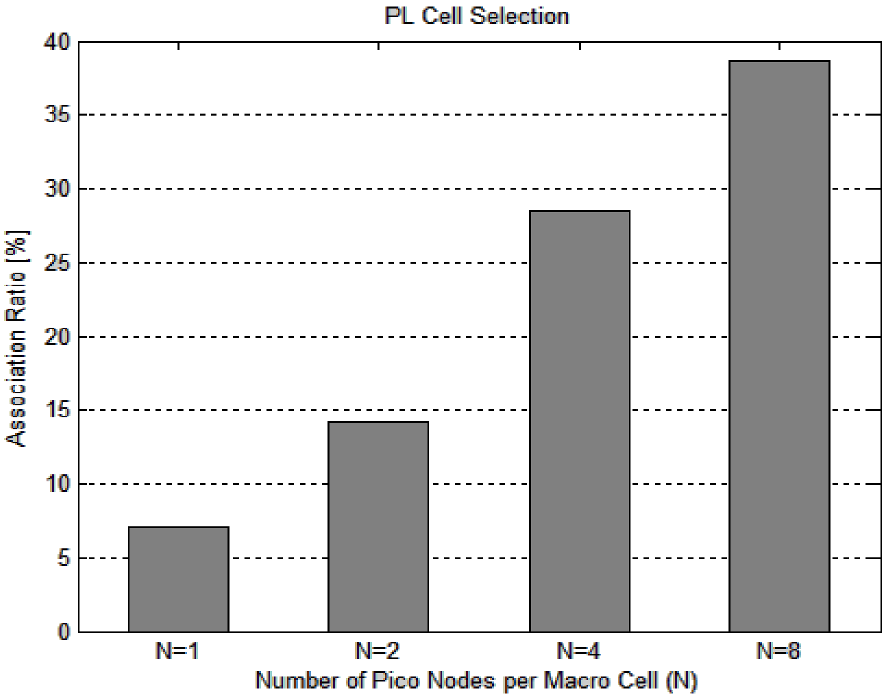

Figure 3.14. Association ratio of pico node under different pico numbers for PL based cell selection method

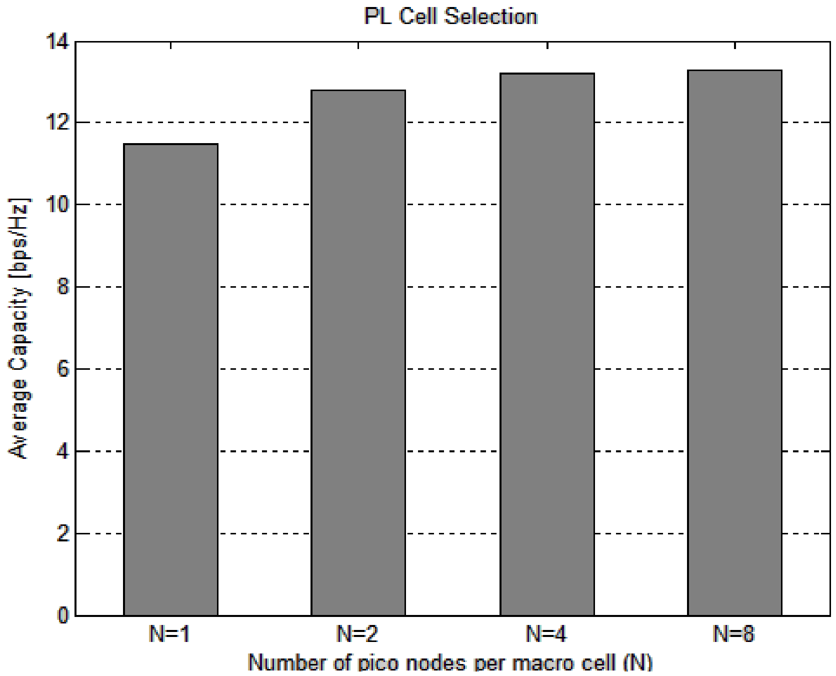

Figure 3.15. Average capacity under different pico numbers for PL based cell selection method

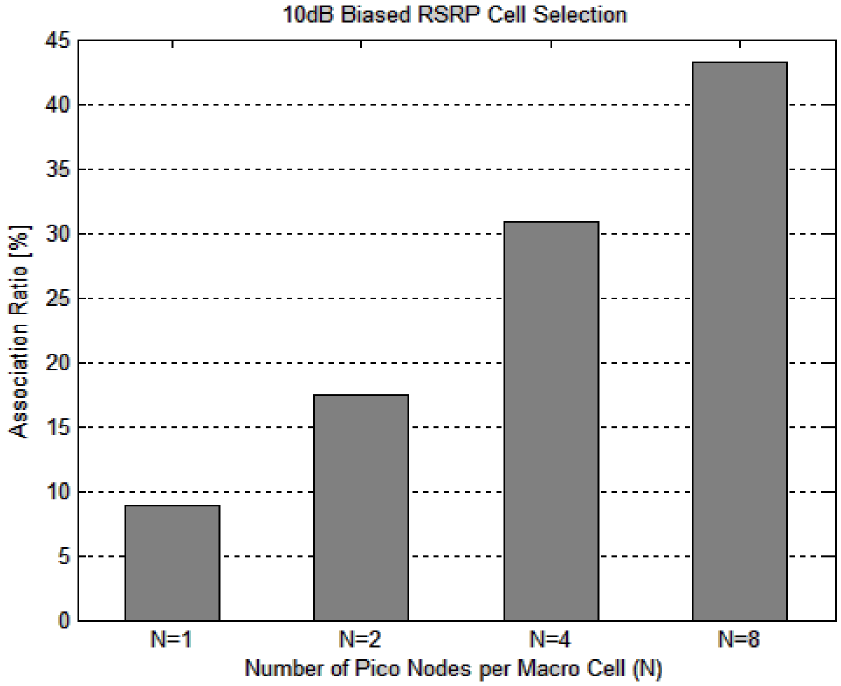

Figure 3.16. Association ratio of pico node under different pico numbers for 10dB biased RSRP cell selection method

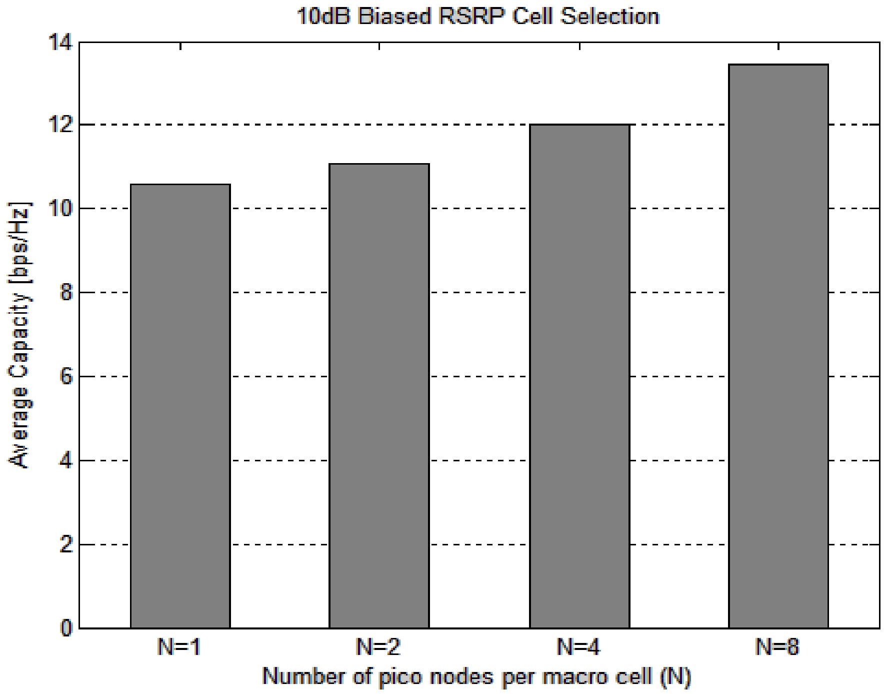

Figure 3.17. Average capacity under different pico numbers for 10dB biased RSRP cell selection method

Six pico cells in a macro coverage area are considered in Figure 3.18 and 3.19. The result shows same performance as scenario-1.

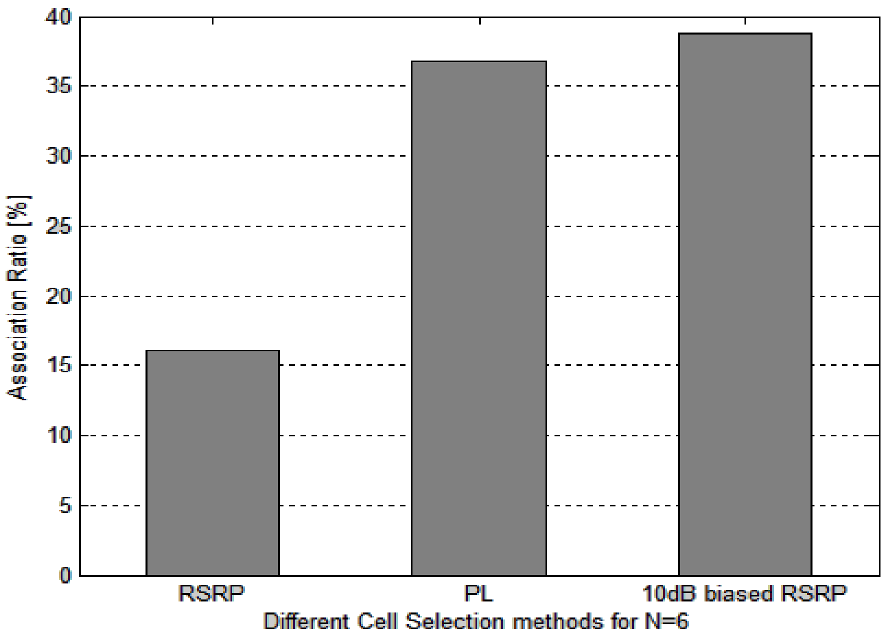

Figure 3.18. Association ratio of pico node for different cell selection methods

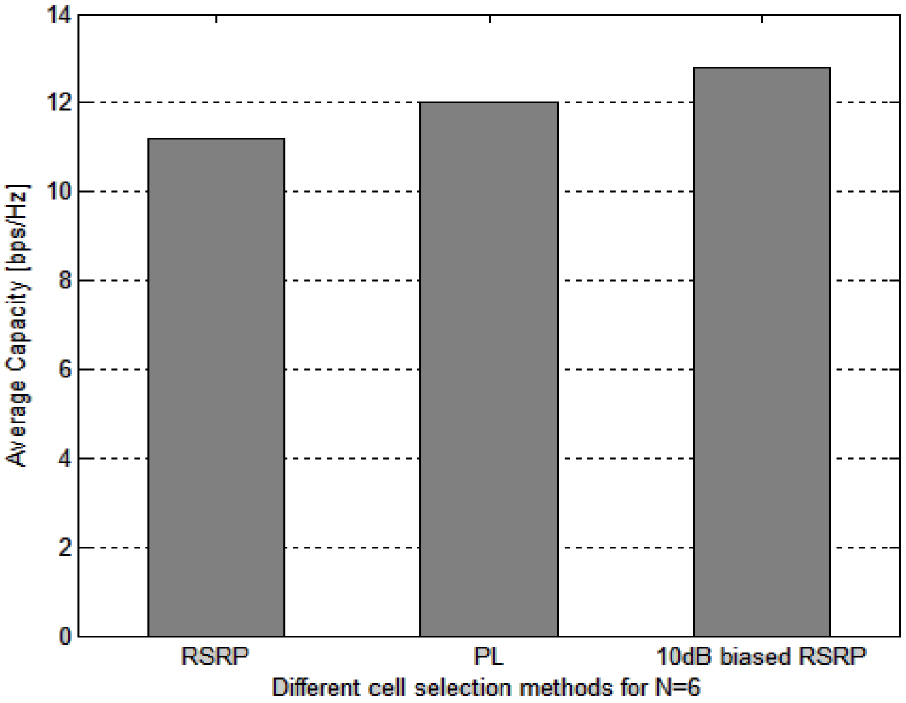

Figure 3.19. Average capacity for different cell selection methods

In this chapter, the ascendancies of different deployment options are shown through simulations.Results show that the perfection of Het-Net strongly confides on the network scenarios and configurations.More specifically, system capacity does not increase linearly with pico numbers, which exposes the tradeoff between network performance and deployment cost. Hence, they should be carefully considered during the network deployment.

CHAPTER 4

INTERFERENCE COORDINATION THROUGH CELL SELECTION FOR HETEROGENEOUS NETWORKS

Heterogeneous network can be considered with a mix of macro cells and low-power, low-cost pico cells, to improve the data rates and cell coverage and offer reduced user rate starvation. Also, to encourage data offloading from macro to pico, CRE can also be introduced. However, the users in CRE region face severe interference from macro cell as they use the same frequency. The result is degradation of the system offloading gain. In order to improve the offloading gain, ICIC for CRE UEs is proposed in Het-Net downlink. Hence, it is also important to consider ICIC in the cell selection methods.

In this chapter different ICIC techniques for CRE UEs are discussed broadly. Moreover, ICIC management through cell selection is the main attraction of this chapter.

4.1. Sources of Interference

Open access is the general operating mode of pico cells, which means all users of a given operator, can access to them. It is helpful to renounce DL interference as end-users always connect to the strongest cell, thus avoiding the Closed Subscriber Group (CSG) interference issue. In Het-Net being connected to the cell which provides the robust DL Received Signal Strength (RSS) may not be the proper technique. Since, users will lean to attach to macro cells and not to those cells being at the shortest path loss distance. This is because of the large transmission power difference between macro cells and pico cells. Hence, traffic load will be bristly distributed and macro cells will be overloaded [12].

Arising matter due to the power differences among nodes in Het-Nets can be handled with specific cell selection methods that allow user association with cells. A manifestation under this exploration is ‘range extension’, where an offset is added to the pico cell's RSS in order to increase its DL coverage footprint (already discussed in previous chapter) [23]. Along with the benefits of range extension, the disadvantage high inter-cell interference comes, that the macro layer imposes on the users in the range extension area of the Pico layer. Figure 4.1 illustrates the overall scenario for better understanding by considering two users in macro coverage area.

As user 1 is positioned nearest to the Pico-eNB it is called "center pico user", which is not affected much by the Macro-eNB interference as the downlink received power from the Pico-eNB is higher than the received power from the Macro-eNB. On the other hand, User 2 is placed in the range extension area, far away from the Pico-eNB. Nevertheless, the Pico-eNB will be selected by this user terminal due to bias association, while the downlink power received by that terminal from the Macro-eNB is much higher than the power it receives from the Pico-eNB. This makes the user in the range extension area more prone to interference from the Macro-eNB. The main focus of this chapter is to discuss some methods to minimize this interference.

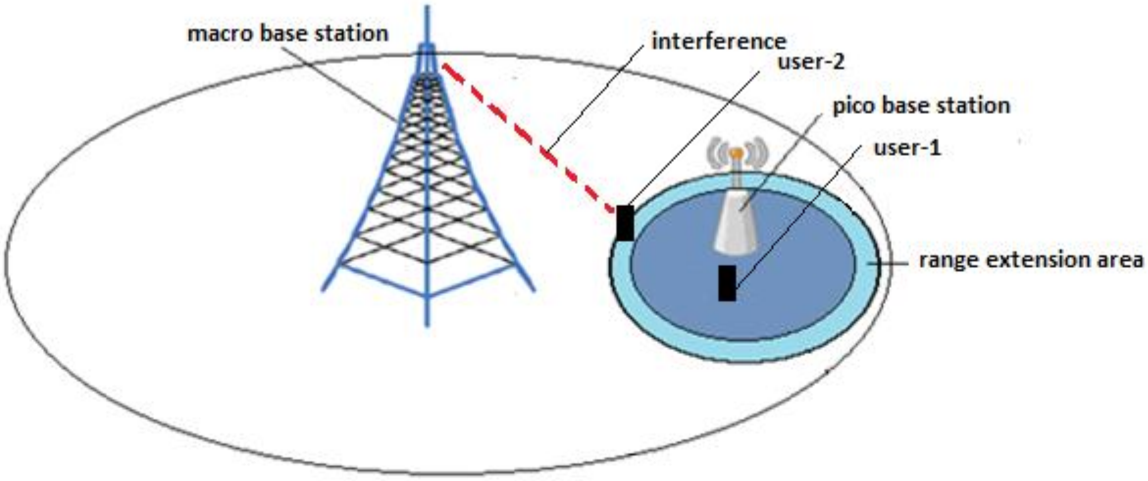

Figure 4.1. Range extension interference

Types of Interference

In general, two types of interference can be seen in macro-pico Heterogeneous Network [24]:

(a) Co-tier interference: Appears among the network elements that belong to the same tier in the network. For example in a pico cell network, co-tier interference occurs with neighboring pico cells.

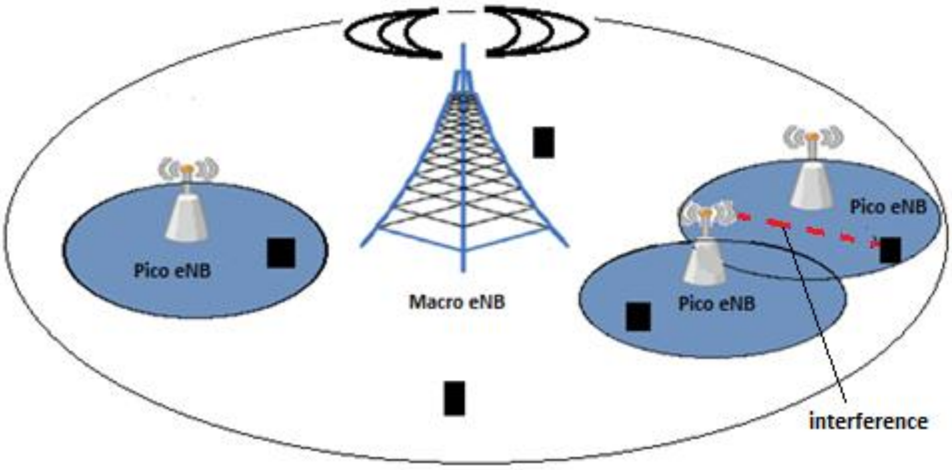

Figure 4.2. Co-tier interference in macro-pico Het-Net

(b) Cross-tier interference: Occurs among network elements that belong to different tiers of the network, such as interference between pico cell and macro cell in a macro-pico Het-Net as shown in Figure 4.3. For example, when a terminal is positioned in an edge area of a pico cell, access from the pico cell can be disconnected due to interference from the macro cell. Figure 4.1 (range extension interference) is also a good example of cross tier interference.

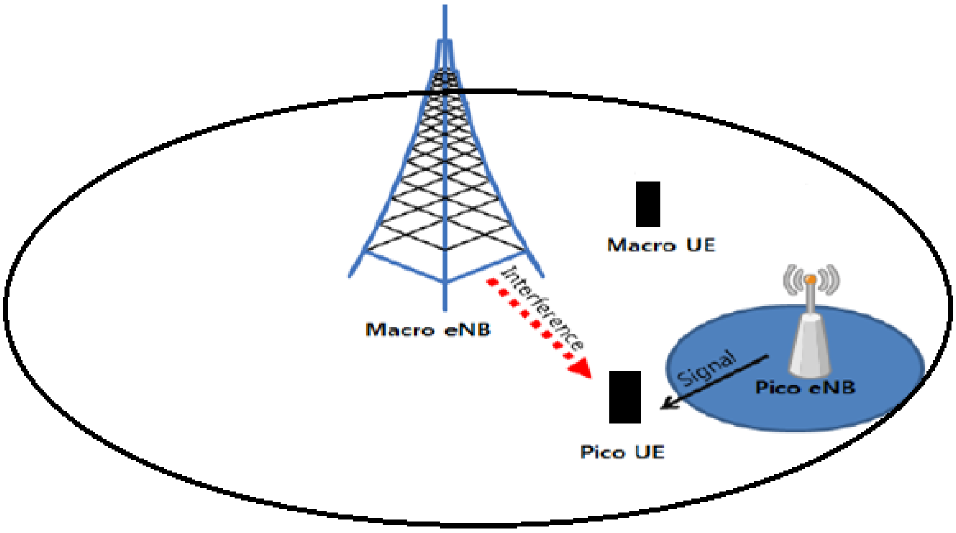

Figure 4.3. Cross tier interference in macro-pico Het-Net [26]

For Het-Net, traditional radio resource management techniques are not suitable to overcome these interferences. Therefore, it is necessary to resort an effective and robust interference management scheme that could moderate the co-tier interference and reduce the cross-tier interference as well, in order to enhance the throughput of the overall network.

4.2. Interference Coordination Techniques

The interference problems discussed above may remarkably degrade the overall Het-Net performance.Hence, it is required to use ICIC techniques to ensure the proper operation of the network. Individual attention should be given to the mitigation of inter-cell interference in the control channels. Otherwise, UEs may declare radio link failure under exquisite interference conditions and experience service outage due to the unreliable DL control channels [12].

Moreover, it is necessary that UEs are able to sense, detect and report information to their servers caring potential interfering cells being present in their vicinity. The UE serving cell in co-operation with the potential interferers will coordinate their resource allocation in terms of power, frequency and time to boost network capacity and moderate user outages.

To ensure the facility of this coordination between Het-Net cells, informative data need to be exchanged among them. Therefore, macro cells are connected to pico cells through the X2 interface. The ICIC messages destined in LTE Release-8 can be exchanged via the X2 interface for DL as Relative Narrowband Transmit Power (RNTP) Indicator [27]. RNTP indicator transmitted by a definite cell is used to instruct the neighboring cells on whether the transmit power for specified Resource Blocks (RBs) will be set below a certain threshold value.

Interference control technology of LTE-Advanced system is explained in 3GPP. Fractional Frequency Reuse (FFR) and RNTP for interference control are supported by 3GPP with its REL-8/9. These methods are used to minimize the interference level by regulating the signal level that is transmitted through a certain frequency resource. Pico cells are deployed over the existing macrocell and share the same frequency spectrum in HetNet, hence face severe interference. Interference management method is limited in the frequency domain due to spectrum scarcity. Hence, LTE REL-10 has introduced the cooperative silencing scheme, using Almost Blank Sub-frames (ABS) in the time domain for interference control [28]. Interference minimizing schemes have been actively discussed in the time domain. It is also explained in section 4.2.2 of this chapter. This selects users protected by ABS and then finds the optimal amount of ABS by assessing the overall system utility.

In addition, Enhanced Dynamic Spectrum Sharing (EDSS) has been introduced for interference management in the pico cell. It combines the DSS with FFR for the Het-Net scenario. DSS considers that the coverage area of the macro center area has no overlap with the coverage area of cell-edge pico cells.

FFR allocates resources in the frequency domain for interference management. On the other hand, Soft Frequency Reuse (SFR) is also utilized to minimize inter-cell interference in the Orthogonal OFDMA based macro system. In FFR, each cell turns off the transmission power of the sub-band using a Frequency Reuse Factor of 3, whether in case of SFR, the overall system efficiency can be increased by this factor, through transmitting with a reduced transmission power. Cross-tier interference can be minimized under this condition. Therefore, we focus on the interference management, allocating resources in the frequency and time domains for Het-Net.

4.2.1. Frequency Domain Multiplexing Intercell Interference Coordination

In this scheme, control channels and physical signals such as synchronization signals and reference signals of different cells are assigned in suppressed bandwidths [12].Which ensures totally orthogonal transmission of these signals at different cells.

Carrier Aggregation (CA)

The fundamental FDM interference reduction technique used in LTE-Advanced is carrier aggregation. This is the most glorious feature of LTE advanced which enables an LTE-Advanced UE to be connected to various carriers concurrently.

The initial idea is to aggregate the different component carriers and conjointly use them for transmission to and from single terminals. Upto 5 transmission components can be aggregated whether they belong to the same frequency range or not. This feature permits the transmission bandwidth to reach 100 MHz which ensures to make use of the fragmented spectrum. Since, operators with fragmented spectrum can use this feature to offer high data-rates by summing all the small spectrum fragments into a sufficiently large component.

Scheduler based fast switching between carriers without time consuming handovers is permitted in CA as well as resource allocation across carriers. That means a node can appoint its control information on a carrier and its data information on another carrier.

In a Het-Net scenario, CA is executed by dividing the available spectrum into two separate component carriers. The primary component carrier f1 and the secondary component carrier f2 are assigned to several network layers at a time as shown in Figure 4.4.

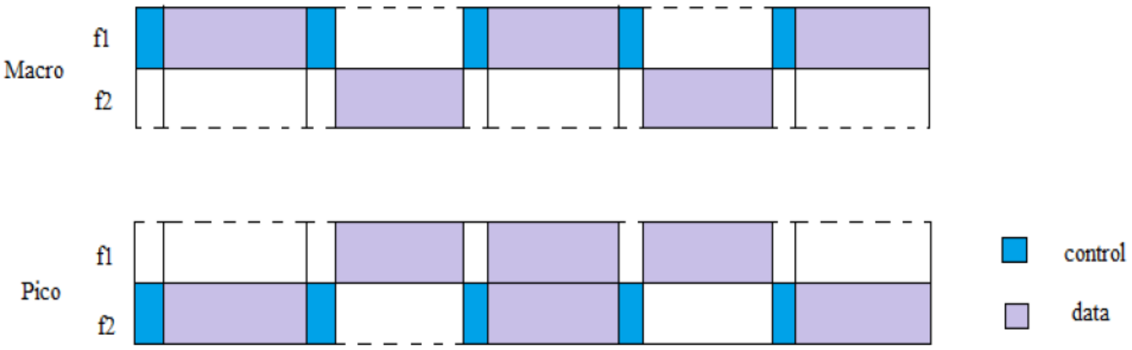

Figure 4.4. Illustration of eIIC based on carrier aggregation

Two component carriers f1 and f2 and two cases, macro layer usage and pico layer usage are considered here. Five sub-frames are placed in each carrier and are distributed in control part and data part.

As shown in the Figure, the macro layer can schedule its control information on f1 and schedule its users on both f1 and f2. Therefore, scheduling control and data information on different component carriers ensures interference control for both macro and pico layers.

It is also possible to schedule center pico user's data information on the same carrier that the macro layer schedules its users as shown in the third sub-frame in the Figure. As the interference from the macro layer on center pico users can be tolerated, pico users in the range extension areas are scheduled in the other carrier where the macro users are not scheduled.

The drawback of CA with cross carrier scheduling is that it is only supported by release 10 terminals [26].

Resource Allocation Based on Soft Frequency Reuse (SFR)

In SFR, frequency band is assigned into macro and pico cell based on SFR for inter-cell interference management as depicted in Figure 4.5 (a). The macro cell coverage is partitioned into a center zone and edge region, each of which includes three sectors. They are denoted by C1, C2, C3 and E1, E2, E3 respectively. The whole frequency band is divided into three sub-frames: A, B, and C.

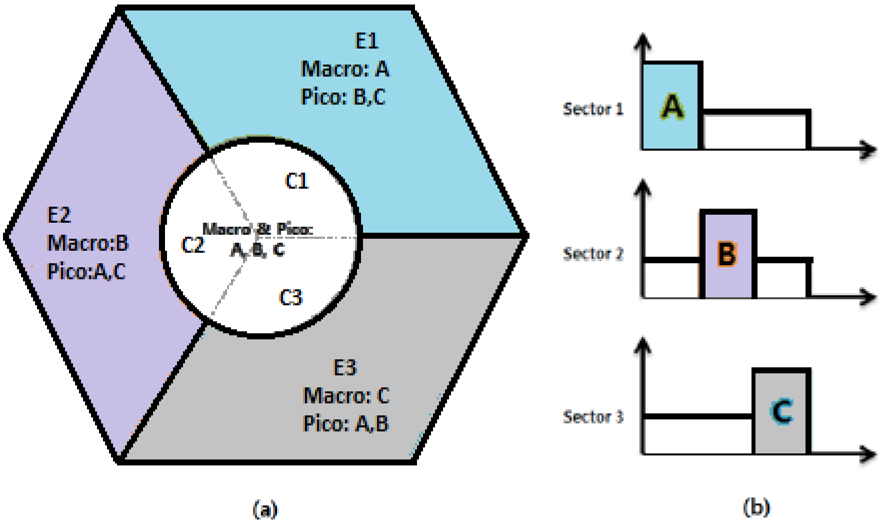

Figure 4.5. Resource allocation based on SFR (a) frequency planning, (b) power allocation

Each macro cell sub-area is assigned by a different frequency sub-band according to the SFR. In the center zone, a reuse factor of one is applied whether the edge region uses a factor of three. The entire frequency band is assigned in the center zone C1, C2 and C3 and sub-bands A, B and C are engaged in the E1, E2 and E3 regions respectively. Moreover, the aggregate system efficiency is improved by decreasing the transmission power in the center zone of the macro cell [26].

At this situation, sub-bands that are not used in the macro cell sub-area are chosen by pico cells. For example, when a pico cell is located in the region E1, it uses sub-bands B and C, while the macro cell uses sub-band A.

4.2.2. Time Domain Multiplexing Intercell Interference Coordination

As discussed as in chapter-2, the UEs connected to pico cells through CRE experience severe interference from the adjacent macro, since the received signal power of the macro cell is higher than that of the connecting pico cell as shown as Figure 4.1. Hence, there is a need for solutions that can improve the SINR of these CRE UEs and ensure fairness.

Time domain sub-frame blanking, also called time domain resource partitioning at macro is considered as one of the solutions in enhanced inter-cell interference coordination (eICIC) techniques within LTE-A to overcome the interference from macro eNB [31] [33]. This assigns different resource blocks between different power class cells. In particular, a set of sub-frames denoted as almost blank sub-frames (ABSs), are muted at macro nodes so that, pico users in cell expanded area can be served within these interference protected sub-frames.

This sub-frame blanking can also be applied in cell selection methods to ensure better system performance, which is described below.

4.3. Interference Coordination through Cell Selection

CRE commences an offset value to the reference signal received power (RSRP) which is used to select the non-optimum cells in the downlink [26]. Nevertheless, the optimum offset value differs for different geographical locations between macro cells, pico cells and their UEs, as the interference levels from the macro and pico cells also differ. Therefore, in this section cell selection methods associated with one of the ICIC techniques called time domain sub-frame blanking is investigated. This method allows pico cell sending data to the UEs via protected resources (ABS), although the macro cell send data to the UEs through other non-protected resources (Non-ABS) which is shown in Figure 4.6.

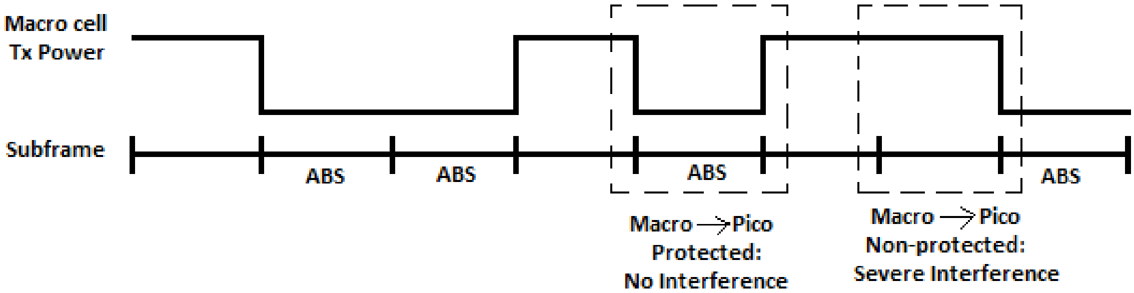

Figure 4.6. Measurement resources for cell selection

Signal-to-Interference-Plus-Noise Power Ratio (SINR)-Based Cell Selection through IC

The average received SINR ensures obtaining accurate channel quality for cell selection. This scheme is sought as a reference scheme, though is not specified in LTE. The offset value α_{SINR} is introduced in order to obtain the offload effect from macro to the pico cells. The UE selects the cell index based on the following criteria:

$$u_{SINR} = arg \max_{0 \leq u \leq U} \gamma_{u,k} \qquad \forall k \tag{4.1}$$

where,

$$\gamma_0 = \gamma_{Non-ABS}$$

$$\gamma_{1,2,\ldots,U} = \gamma_{ABS} + \alpha_{SINR}$$

$\gamma_{u,k}$, $\gamma_{Non-ABS}$ and γ_{ABS} respectively represent the SINR value of the *u*-th cell to be used for cell selection, average SINR of the macro cell where no protection is applied and the average SINR of the *u*-th pico cell where ABS is applied.

Reference Signal Received Quality (RSRQ)-Based Cell Selection through IC

RSRQ is one of the LTE specified cell selection methods. Other one is RSRP. RSRQ is determined by RSRP divided by the total received power, received signal strength indicator (RSSI) [28].

$$RSRQ = \frac{RSRP}{RSSI} \propto \frac{S}{S + I + N} = \frac{SINR}{1 + SINR} \tag{4.2}$$

where *S*, *I* and *N* represent the received power of the desired cell, interference and noise power respectively. According to Equation (4.2), the increase in the SINR increases RSRQ. Hence, RSRQ-based cell selection functions in the same manner as the SINR-based cell selection without offset. Adding offset value α_{RSRQ}, the UE selects the cell index on following basis:

$$u_{RSRQ} = \arg\max_{0 \leq u \leq U} \rho_{u,k} \qquad \forall k \tag{4.3}$$

where,

$$\rho_0 = \rho_{Non-ABS}$$

$$\rho_{1,2\ldots,U} = \rho_{ABS} + \alpha_{RSRQ}$$

where, $\rho_{u,k}$, $\rho_{Non-ABS}$ and ρ_{ABS} represent the RSRQ value of the u-th cell to be used for cell selection, the RSRQ for macro cell in the non-protected resources and the RSRQ in the protected resources for the u-th pico cell respectively.

Due to the different gradient functions of RSRQ and SINR, RSRQ requires different offset values compared to the SINR as shown as Figure below [35].

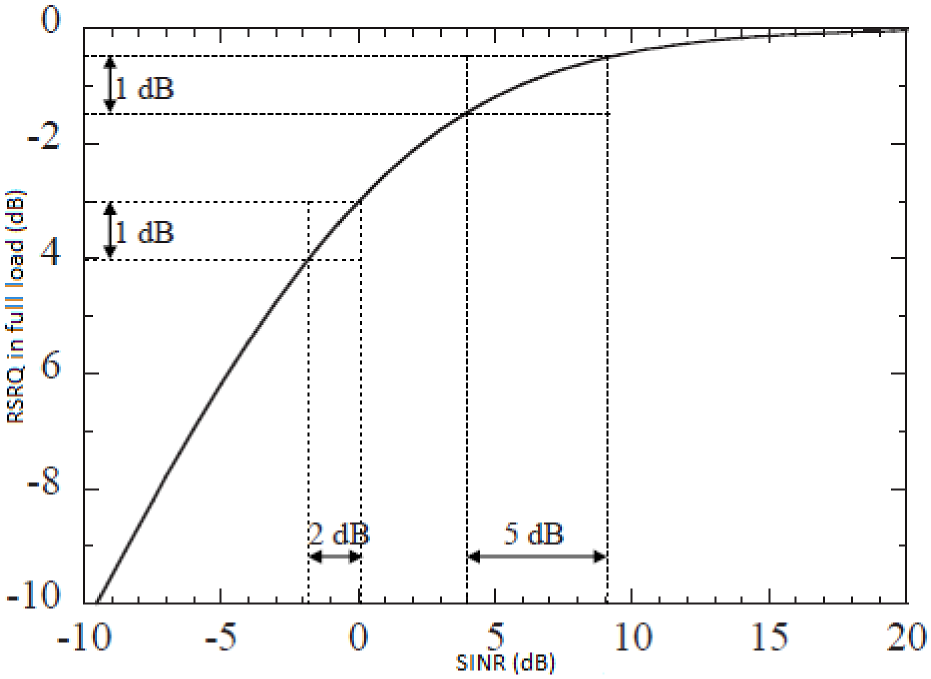

Figure 4.7. Differences in SINR and RSRQ-based cell selection [35]

More UEs with a higher SINR are offloaded to the pico cells in RSRQ-based cell selection compared to SINR based selection.

4.3.1. Interference Coordination Schemes

After performing the cell selection process, the system will have macro-UEs, pico-UEs and pico CRE-UEs. To mitigate the interference which CRE-UEs face in the cell extended region (previously discussed), the next step is to apply interference management schemes among them.

Sub-frame Blanking Scheme

The main idea of sub-frame blanking is, scheduling CRE UEs during ABS transmission of macro eNB. Pico eNB identifies the CRE UEs and makes a request to macro eNB over X2 interface to configure ABS. Macro eNB rejoins by mentioning the location of ABS which is configured using an ABS bitmap, shown in Figure 4.8. Macro also indicates the measurement subset which implies suitable set of sub-frames that can be used for measurements by UEs that suffer severe interference in non ABS sub-frames. Pico eNB can ask macro to increase or decrease the number of ABS.

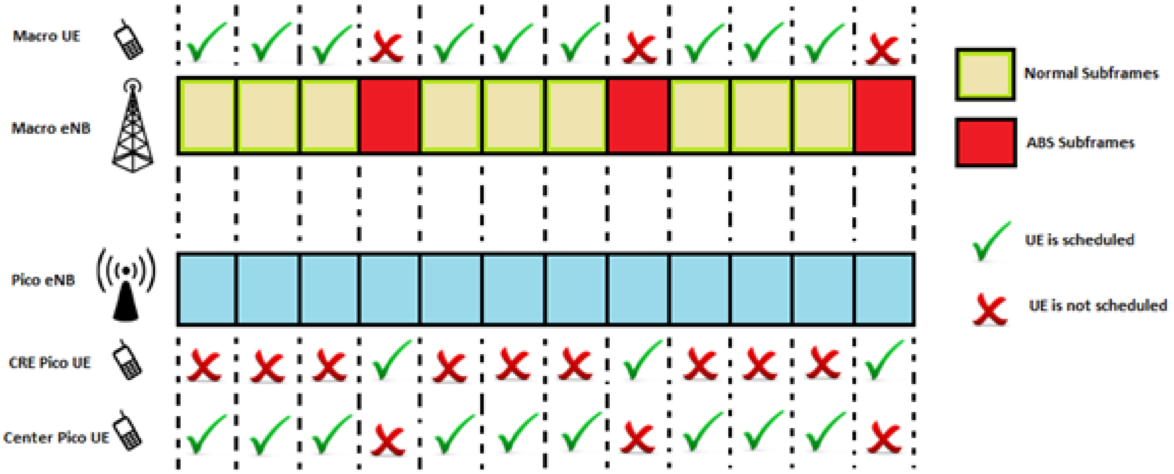

Figure 4.8. ABS pattern for one pico cell over a macro cell

Number of ABS sub-frames to be composed at macro is dominion and an execution issue. Therefore, it is important to consider the density of ABS that should be scheduled. By intuition it depends on macro UE load, pico CRE UE load and pico non-CRE UE load as given as below [16]

$$N_{ABS}^{m} = \left[T_{ABS} \max_{u} min \left\{ \frac{Z_{pCRE}^{u}}{Z_{pCRE}^{u} + Z_{p}^{u}}, \frac{Z_{pCRE}^{u}}{Z_{pCRE}^{u} + Z_{m}} \right\} \right], \qquad 1 \leq u \leq U \tag{4.4}$$

where, T_{ABS} is the ABS periodicity expressed as number of sub-frames, Z_{pCRE}^{u} and Z_{p}^{u} are the CRE and non CRE UE load respectively on u-th pico cell and Z_m is the number of UEs on macro cell.

Due to the ABS transmission, macro eNB sacrifices considerable amount of resources.On the other hand, signaling is also required to setup ABS. This signaling may be negligible for one pico cell in a macro cell, but as the number of picos increase, macro eNB needs to setup ABS and signal for every pico. Therefore, Het-Net faces huge signaling overhead both at macro as well as at each pico cell.

Power Control Schemes

Sub-frame blanking can defend the CRE UEs from macro interference. But this technique comes at the expense of macro resources and additional signaling. Besides these techniques , there are more two ways to improve SINR of CRE user through controlling transmission power.

1) Reducing the transmission power of macro eNB or
2) Increasing the transmission power of pico eNB.

In order to apply the above power control schemes, it is important to calculate power offset of k-th CRE user associated to u-th pico cell in macro cellular area. This power offset can be defined by $\Delta P_{u,k}$ and calculated as follow:

$$\Delta P_{u,k} = P_k^0 - P_k^{p_u} \tag{4.5}$$

where, P_k^0 and $P_k^{p_u}$ are received signal powers of the k-th user with respect to the macro and pico eNB respectively.

Reduced Macro power sub-frame (RMPS)

The idea of RMPS is, instead of stopping the transmission of macro eNB’s data; transmitting data at lower power. This will reduce the loss due to blanking.

Macro-eNB reduces its transmit power in some sub-frames called RMPS based on the power offset value mentioned in Equation (4.5).

$$\tilde{P}_t^0 = P_t^0 - \max_{u,k} \Delta P_{u,k} \tag{4.6}$$

where,
$$P_t^0 = max\{\tilde{P}_t^0, P_{t_{min}}^0\} \tag{4.7}$$

P_t^0 and $P_{t_{min}}^0$ are the transmit power and minimum transmit power by macro eNB respectively. As it is necessary for macro eNB to hold up a big coverage area, transmit power cannot be reduced beyond a minimum value which is shown in Equation (4.7).

Number of RMPS sub-frames to be configured at macro is exactly same as the number of ABS sub-frames which is already mentioned in Equation (4.4).

$$N_{RMPS}^{m} = N_{ABS}^{m} \tag{4.8}$$

Moreover, diminishing the macro power will curtail the cell and affects the coverage of macro cell.

Increased Pico power sub-frame (IPPS)

IPPS scheme is capable to overcome the draw backs which occurs in sub-frame blanking and RMPS techniques. In this method, pico eNB increases its transmit power in some sub-frames referred as increase pico power sub-frames and macro eNB works at its full power. As the pico eNB is a low power node it cannot transmit beyond a maximum value, Equation (4.10) ensures that. Each pico distributes the obtainable sub-frames between CRE and non-CRE users proportionally [16].

$$\tilde{P}_t^{p_u} = P_t^{p_u} + \max_k \Delta P_{u,k} \,, \qquad 1 \leq u \leq U \tag{4.9}$$

where,

$$P_t^{p_u} = min\left\{\tilde{P}_t^{p_u}, P_{t_{max}}^{p}\right\} \tag{4.10}$$

where, $P_t^{p_u}$ and $P_{t_{max}}^{p}$ are the transmit power of u-th pico node and the maximum transmit power by that pico node respectively. The number of sub frames in which u-th pico will increase its transmit power is given in Equation (4.11).

$$N_{IPPS}^{p_u} = \left[T_{ABS} \frac{Z_{pCRE}^{u}}{Z_{pCRE}^{u} + Z_{p}^{u}}\right] \,, \qquad 1 \leq u \leq U \tag{4.11}$$

The procedure of IPPS is simple and independent of macro eNB compared to the procedure to setup ABS or RMPS at macro. In addition, pico has the flexibility to increase transmit power in as many sub-frames as required. Conversely, in case of ABS or RMPS macro may not always blank or reduce power in as many sub-frames as requested by pico.

Though increasing transmit power of picos can cause fragile increases the overall power consumption of the network. This can be eliminated by joint scheduling of CRE and non-CRE UEs in the same sub-frame and, increasing and decreasing power per subcarrier of CRE and non-CRE UEs respectively while keeping the total power constant [16].

4.4. Performance Results

In this chapter 50 UEs in macro cellular area and 10 UEs in each pico cell area are assigned. Then, cell selection techniques through interference coordination are performed to determine CRE users among given macro users. Finally, to evaluate the impact of cell selection method, two different scenarios are considered in the simulations. Scenario-1: one macro-one pico node (Figure 4.9), scenario-2: one macro-four pico nodes (Figure 4.21), considering co-channel allocation and focusing on the downlink operation. Only, cross-tier interference is contemplated here. The simulation parameters of interest are as mentioned in the Table-4.1.

Table 4.1. Simulation parameters for different interference coordination schemes

Parameters	**Setting**
Bandwidth	10MHz
PL and shadowing models	As defined in Chapter-3
Macro transmit power	43dBm
Minimum macro transmit power	37dBm
Pico transmit power	30dBm
Maximum pico transmit power	37dBm
Macro cell radius	1km
Pico cell radius	50m
Number of sub-frames	100
Noise power spectral density, N_0	-174dBm/Hz

Scenario-1

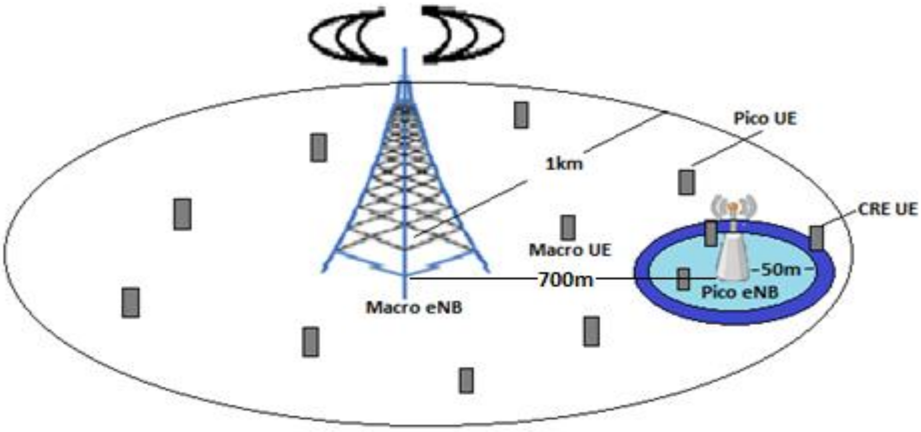

Figure 4.9. Scenario 1-one pico node over a macro cell area

Figure 4.10 and 4.11 represent the effect of cell selection through ABS and effect of different BIAS values on association ratio respectively. Considering Figure 4.7, 1dB and 2.2dB offset value is used for RSRQ based cell selection, whereas SINR performs with 4dB and 8dB respectively.

As RSRP only empowers the received power from each cell and the channel quality of the respective resources are not reflected, IC implementation is not optimum in case of RSRP cell selection. Though, implementation of offset values for the pico cells can be used to recoup for the difference in channel quality between macro and pico cells [26].

On the other hand, SINR and RSRQ both will have more CRE UEs comparing without implementation of IC. Therefore, posterior simulations for cross-tier interference management schemes have done based on IC dependent cell selection.

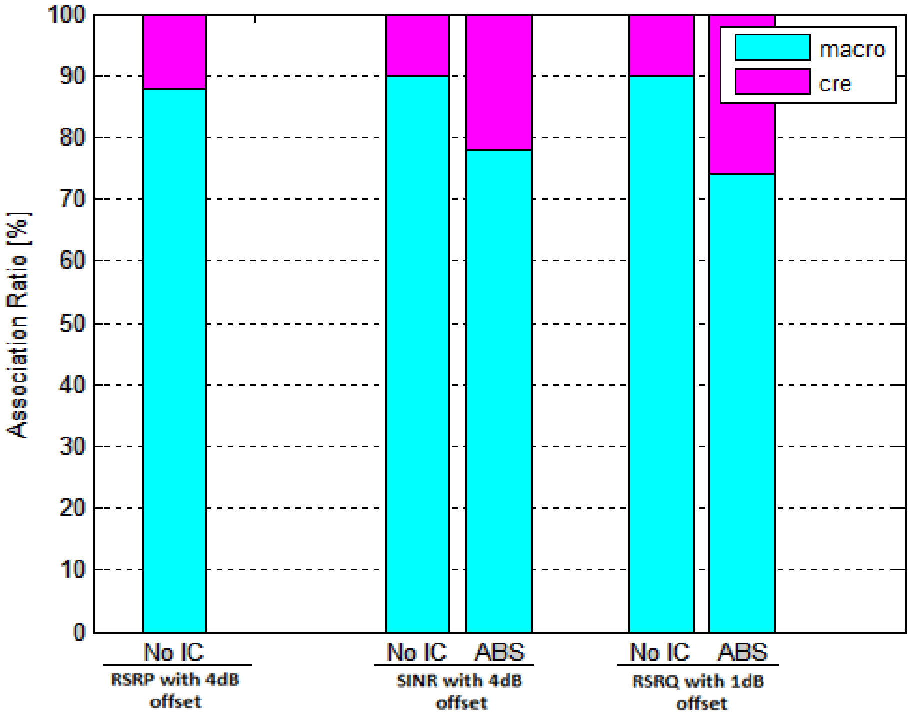

Figure 4.10. Effects of cell selection through ABS

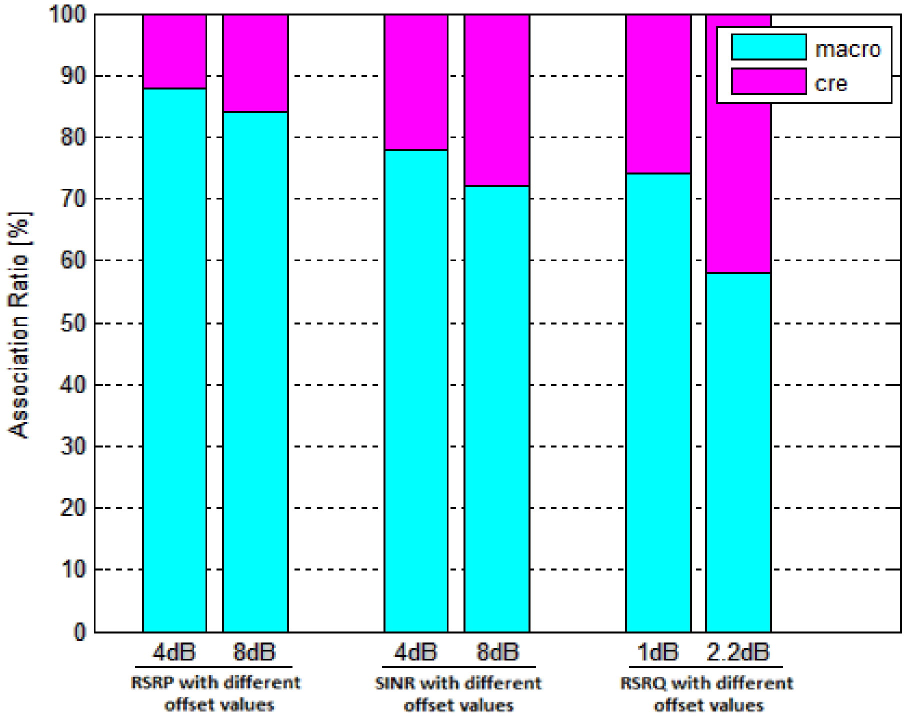

Figure 4.11. Cell selections through ABS for different offset values

To analyze the performance of interference management schemes through cell selection, two power control methods RMPS and IPPS are compared against without blanking (no ABS) and almost blanking (ABS) methods in Figure 4.12 to 4.20 for scenario-1.

Macro UE capacity for mentioned RSRP,SINR and RSRQ cell selection methods are plotted in the Figure 4.12,4.15 and 4.18 respectively. Figures show that the no ABS performs the best, as it does not sacrifice any resources and ABS performs worst, as it blanks the complete sub-frame. RMPS shows better performance than ABS as it reduces loss of resources. No ABS exceeds IPPS, as macro users in IPPS experience larger interference from pico compared to no ABS scheme.

Capacity distribution of pico CRE UEs for RSRP, SINR and RSRQ cell selection methods are plotted in Figure 4.13, 4.16 and 4.19 respectively. No power control is performed to protect CRE UEs from the macro interference in no ABS scheme. Besides that, MeNB stops transmission in ABS sub-frames and CRE UEs are highly protected from macro interference in ABS format. On the other hand, in case of RMPS and IPPS schemes, power levels of macro and pico are declined and boosted in RMPS and IPPS sub-frames respectively by a required amount. It is noticeable that the performance of CRE user is finest in case of ABS and lowest in case of no ABS.

Figure 4.14, 4.17 and 4.20 show the capacity distributions for all UEs under discussed cell selection methods. For all cases, no ABS shows better sum UE capacity compared to ABS scheme. It can be observed that the IPPS scheme achieves better sum UE capacity than ABS and RMPS.

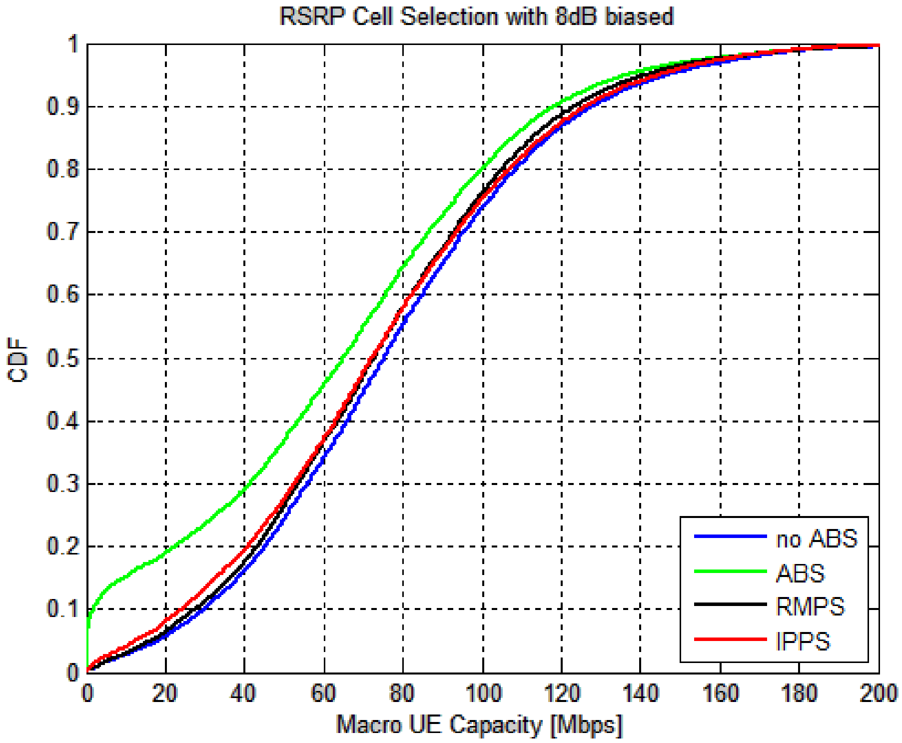

Figure 4.12. Macro UE capacity for RSRP based cell selection

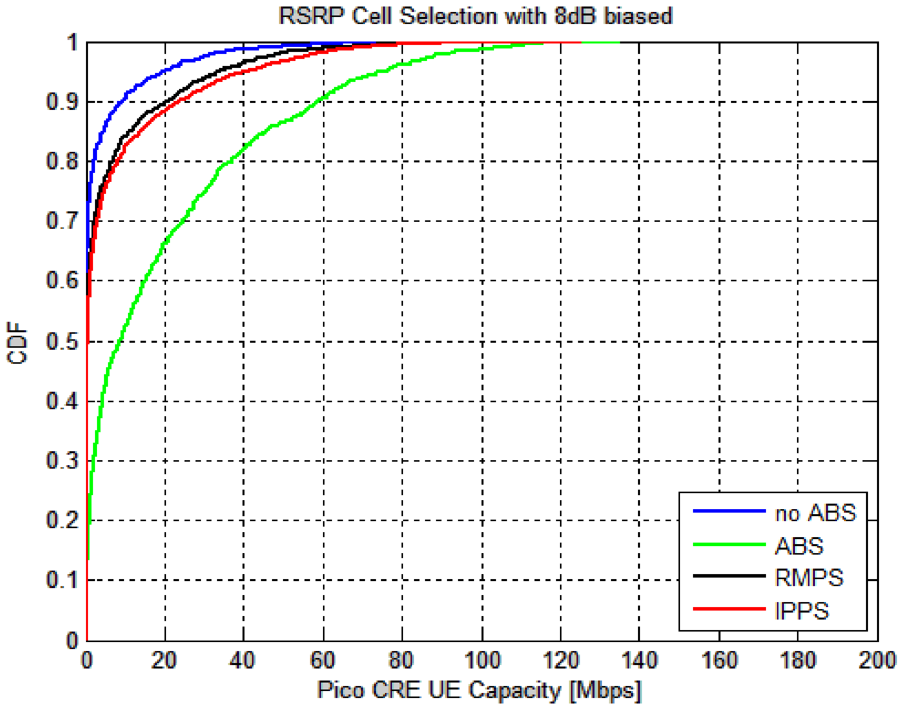

Figure 4.13. Pico CRE UE capacity for RSRP based cell selection

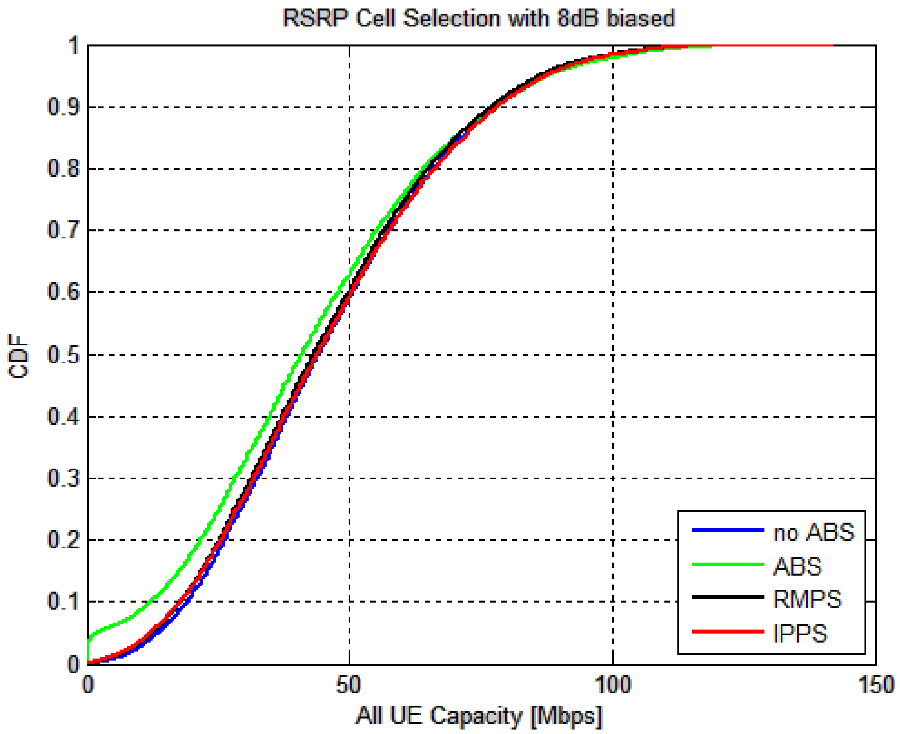

Figure 4.14. All UE capacity for RSRP based cell selection

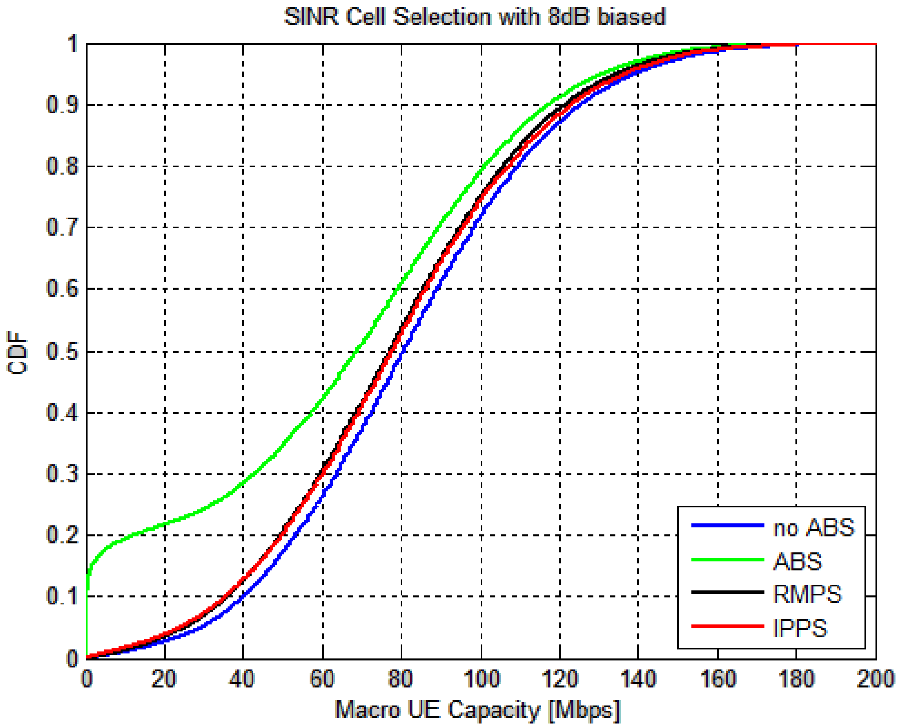

Figure 4.15. Macro UE capacity for SINR based cell selection

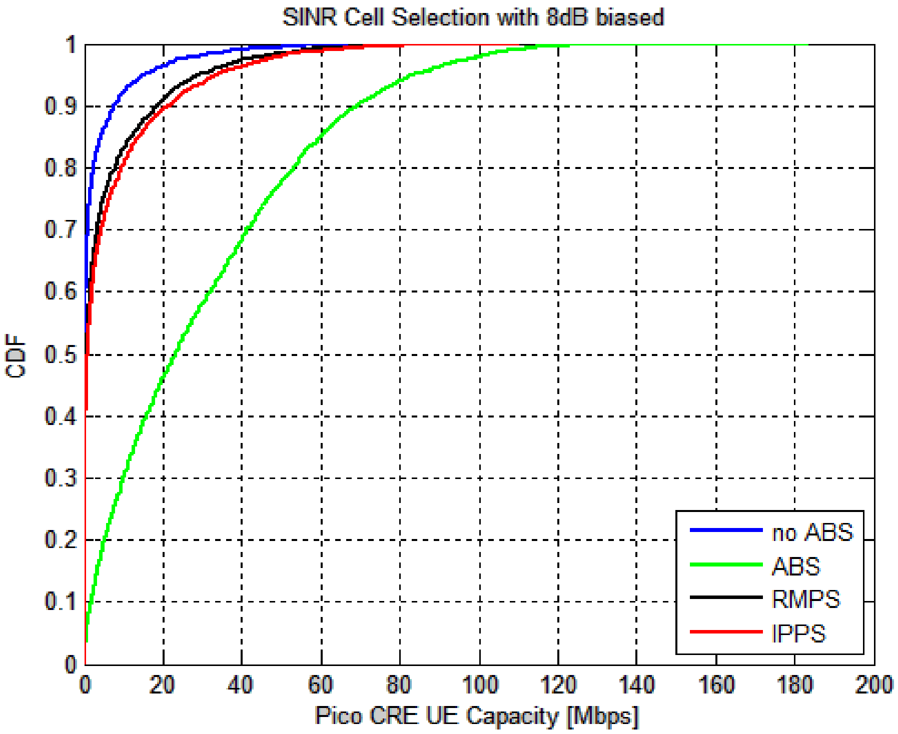

Figure 4.16. Pico CRE UE capacity for SINR based cell selection

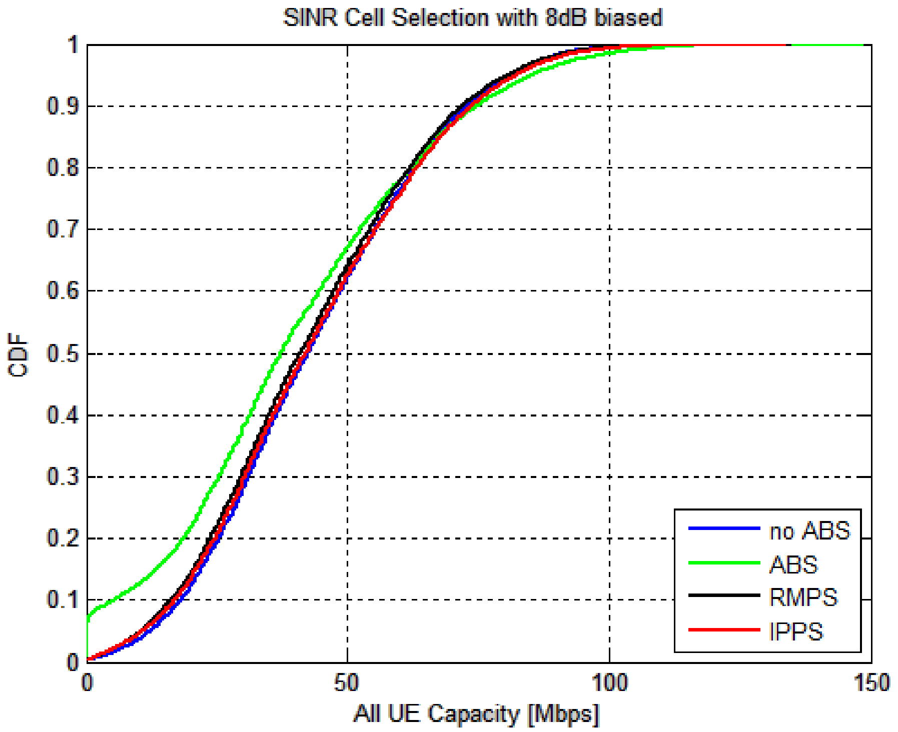

Figure 4.17. All UE capacity for SINR based cell selection

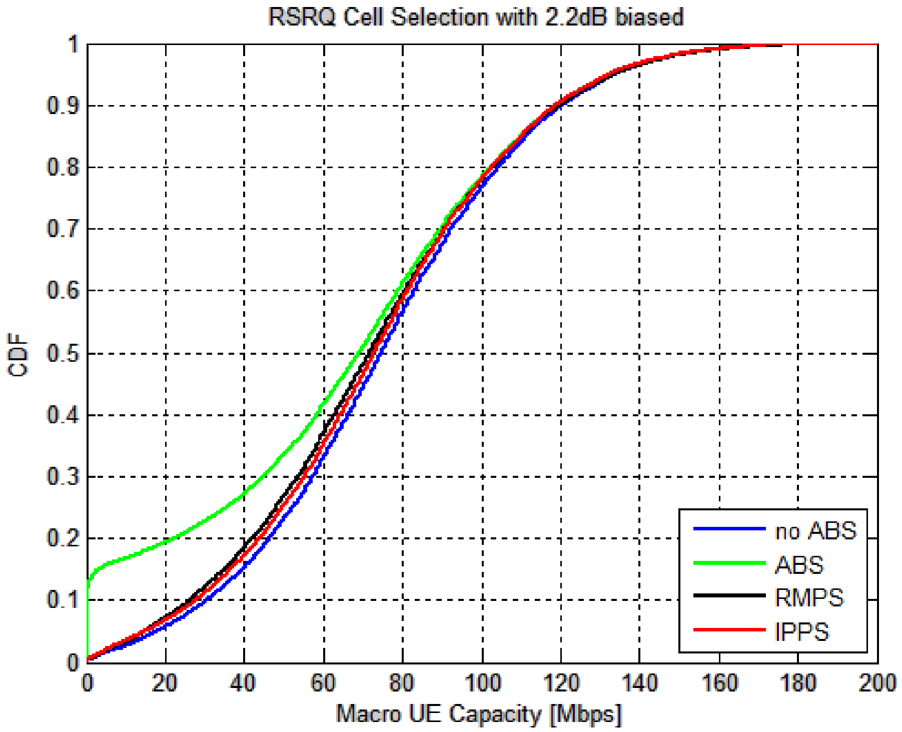

Figure 4.18. Macro UE capacity for RSRQ based cell selection

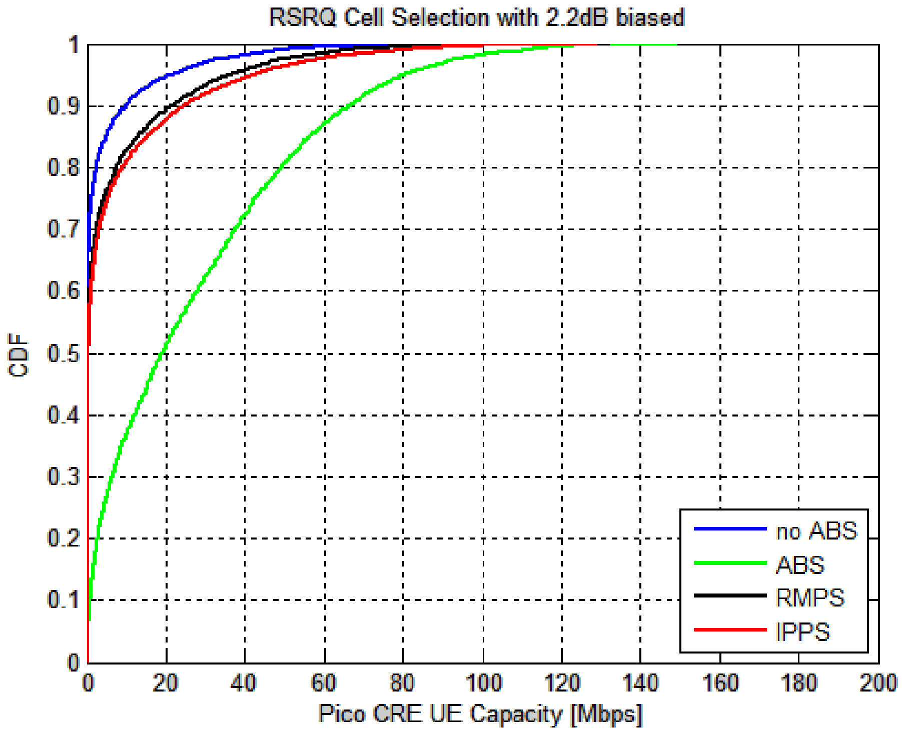

Figure 4.19. Pico CRE UE capacity for RSRQ based cell selection

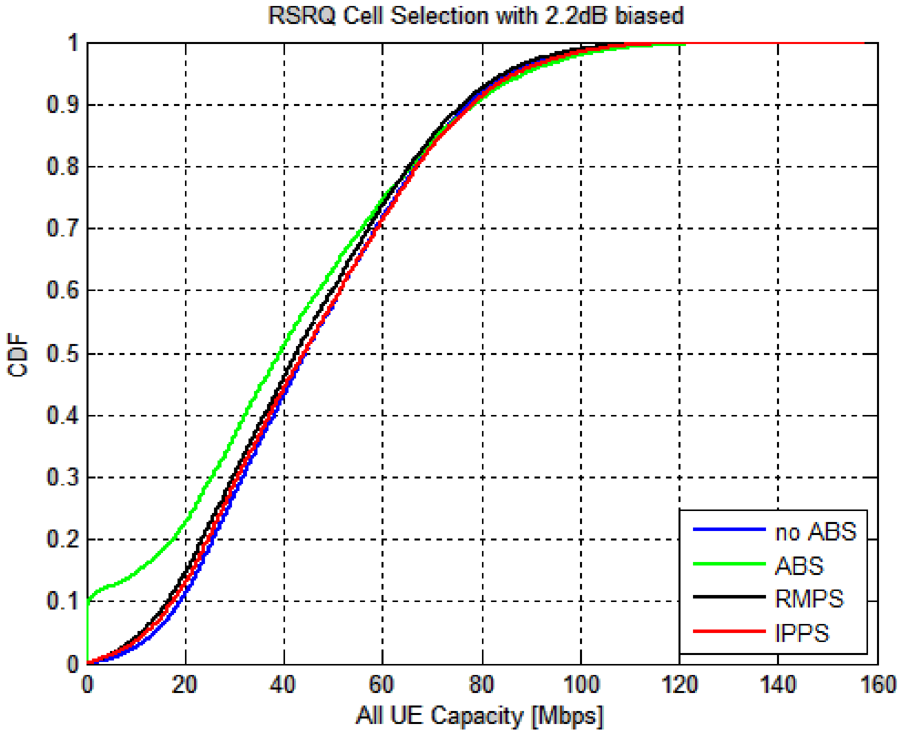

Figure 4.20. All UE capacity for RSRQ based cell selection

Scenario-2

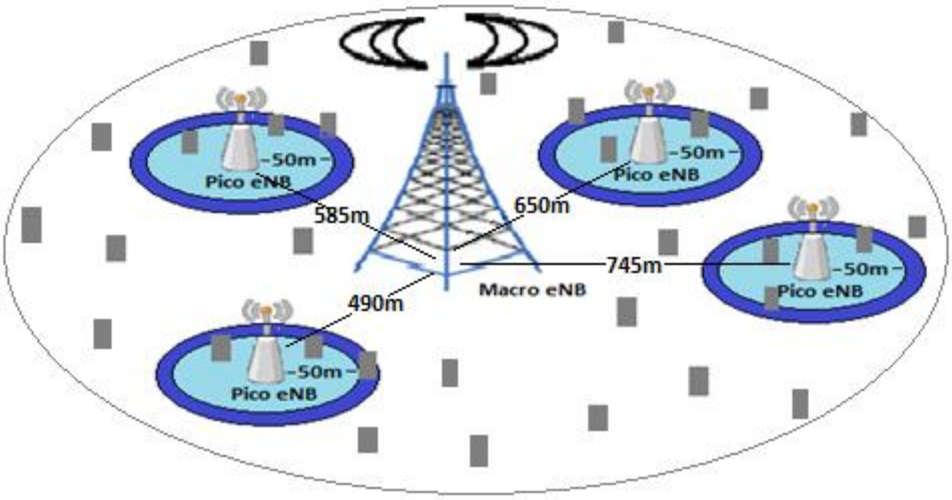

Figure 4.21. Scenario 2-four pico nodes over a macro cell area

Figures 4.22 to 4.32, consider four picos in a macro cellular area. It can be seen even with a higher number of picos , no ABS, ABS, RMPS and IPPS performs same way as scenario-1.

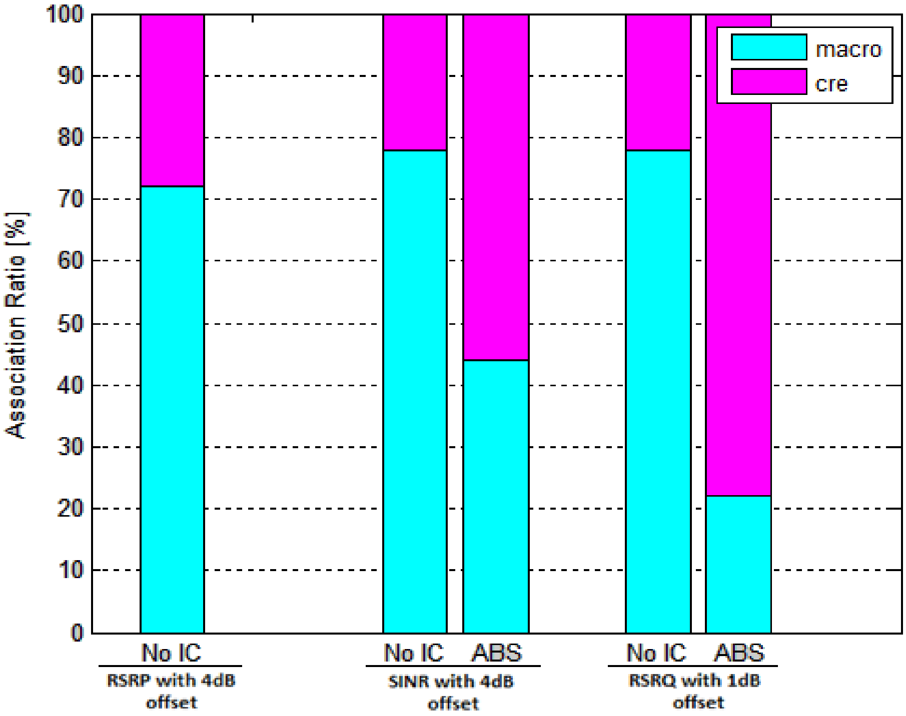

Figure 4.22. Effects of cell selection through ABS

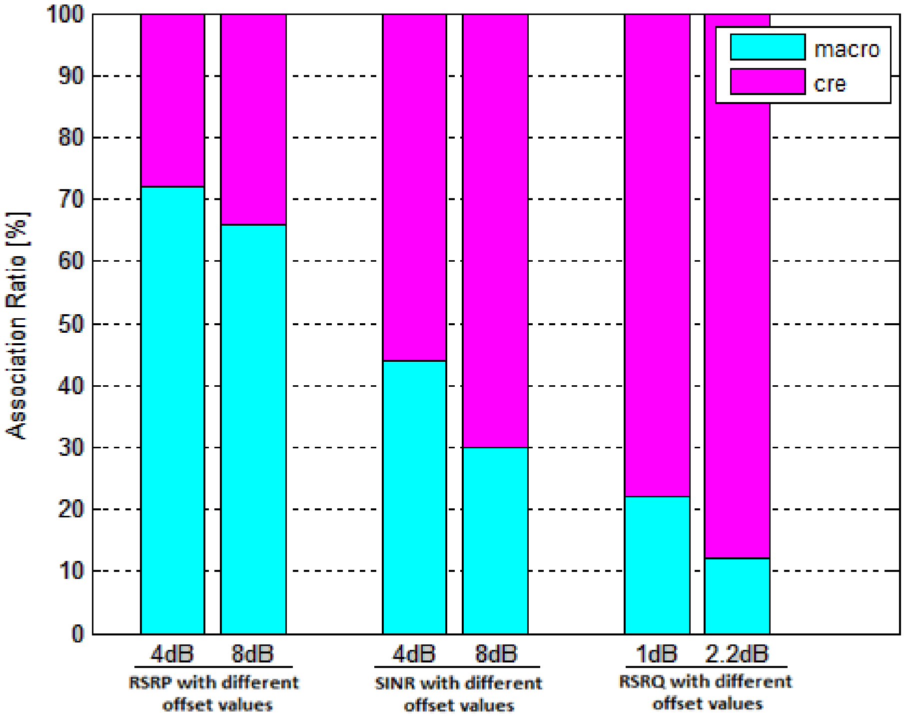

Figure 4.23. Cell selections through ABS for different offset values

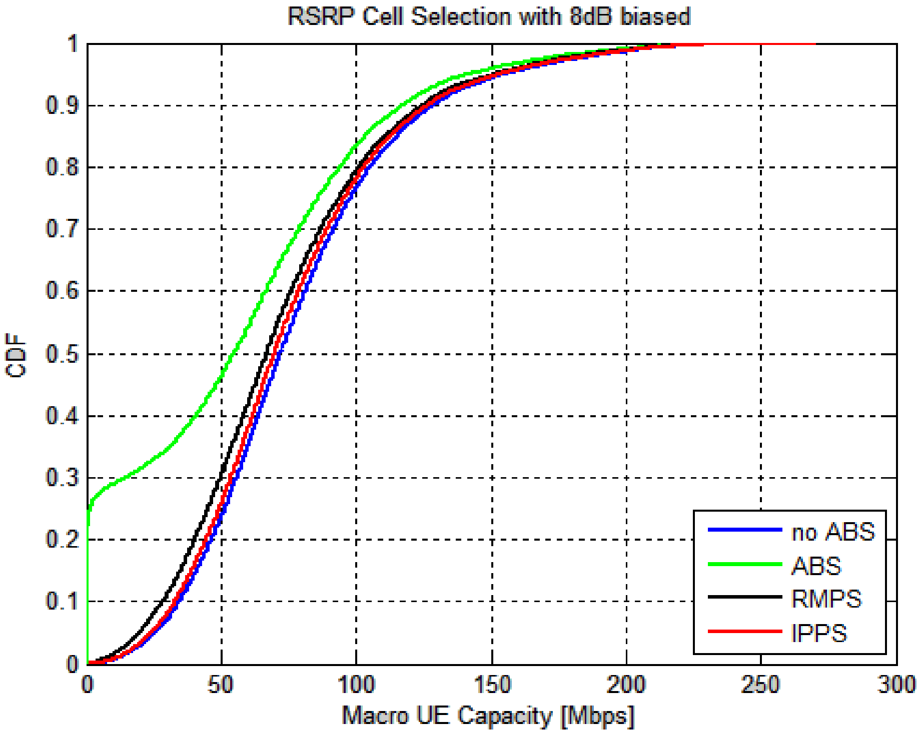

Figure 4.24. Macro UE capacity for RSRP based cell selection

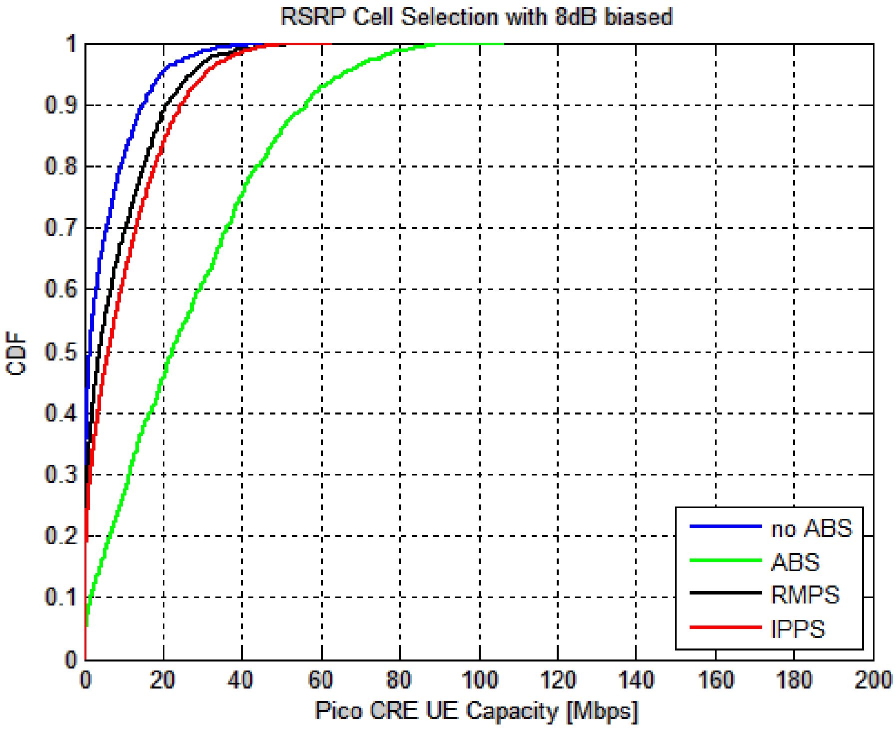

Figure 4.25. Pico CRE UE capacity for RSRP based cell selection

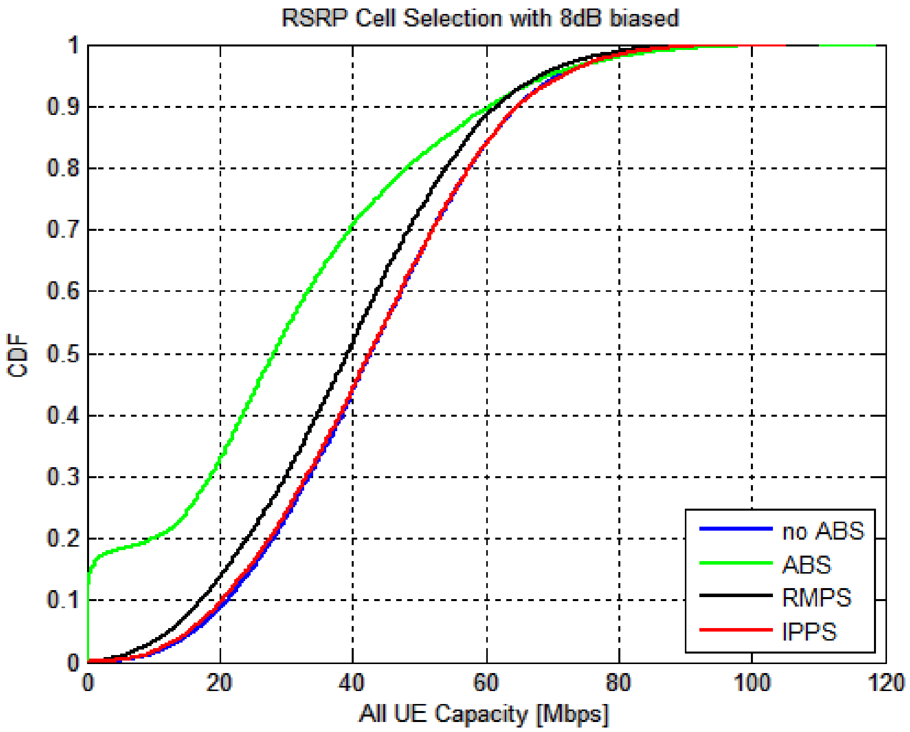

Figure 4.26. All UE capacity for RSRP based cell selection

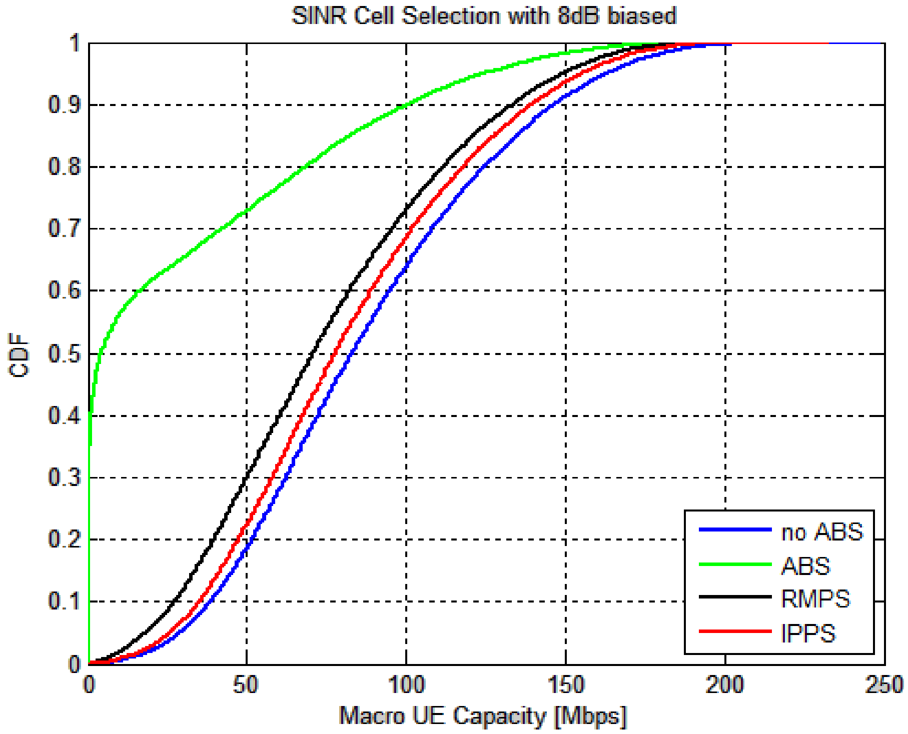

Figure 4.27. Macro UE capacity for SINR based cell selection

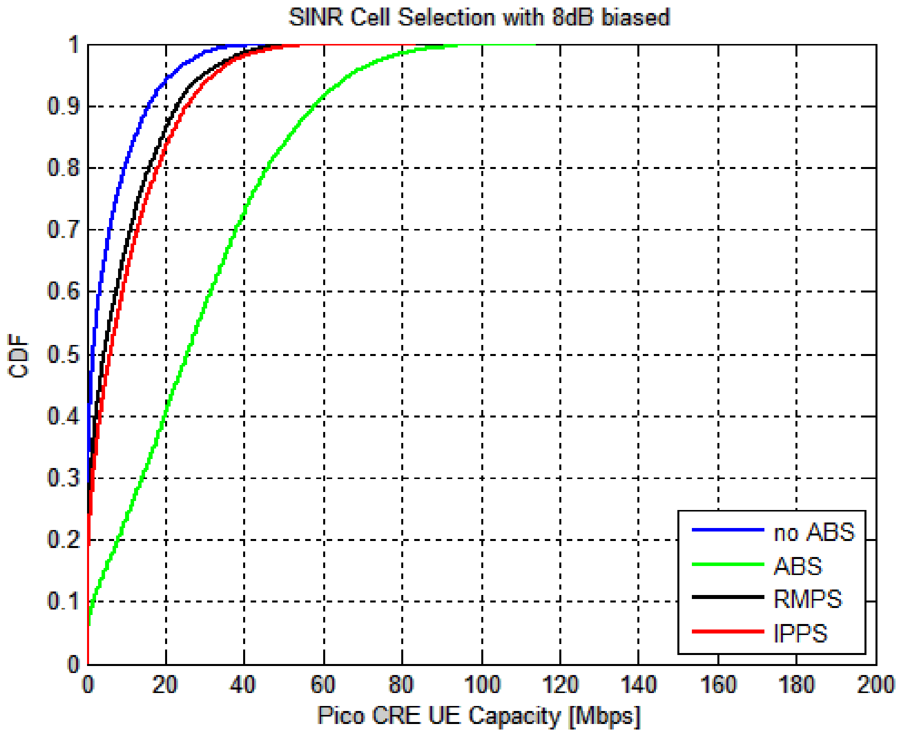

Figure 4.28. Pico CRE UE capacity for SINR based cell selection

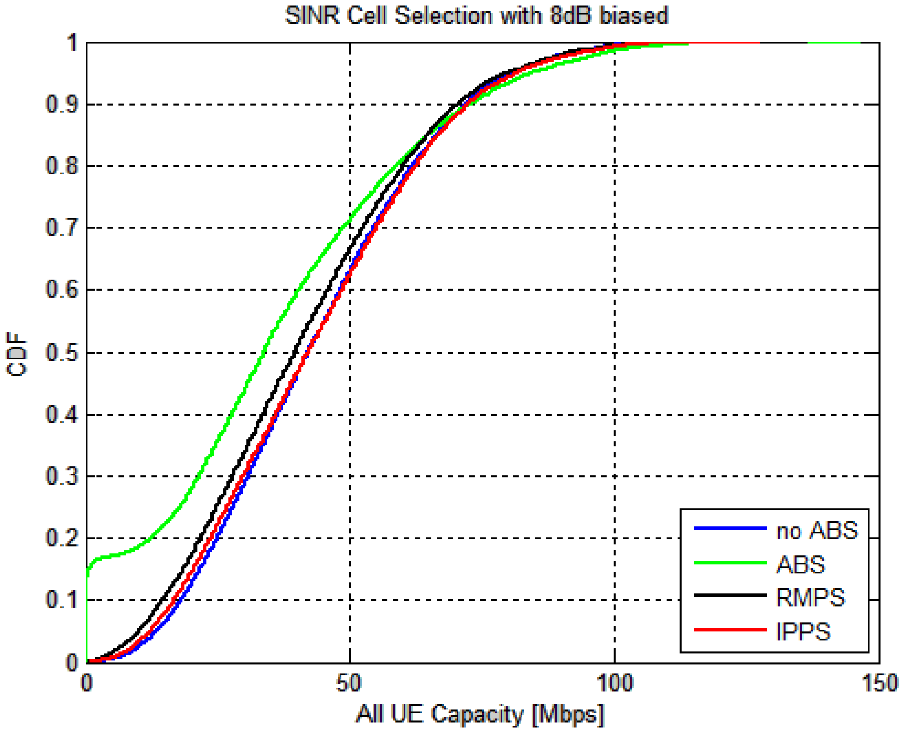

Figure 4.29. All UE capacity for SINR based cell selection

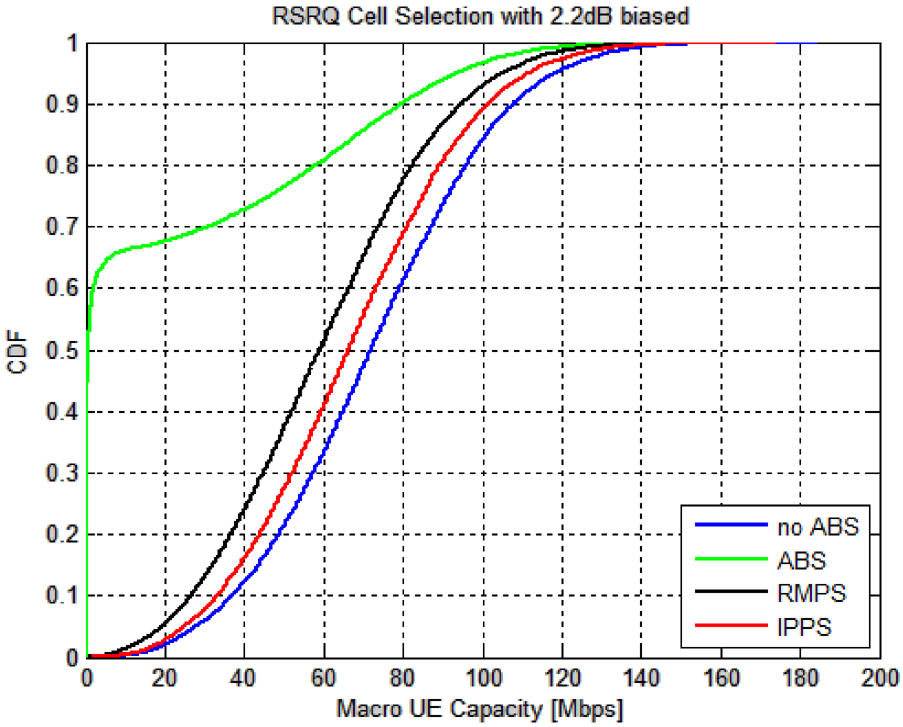

Figure 4.30. Macro UE capacity for RSRQ based cell selection

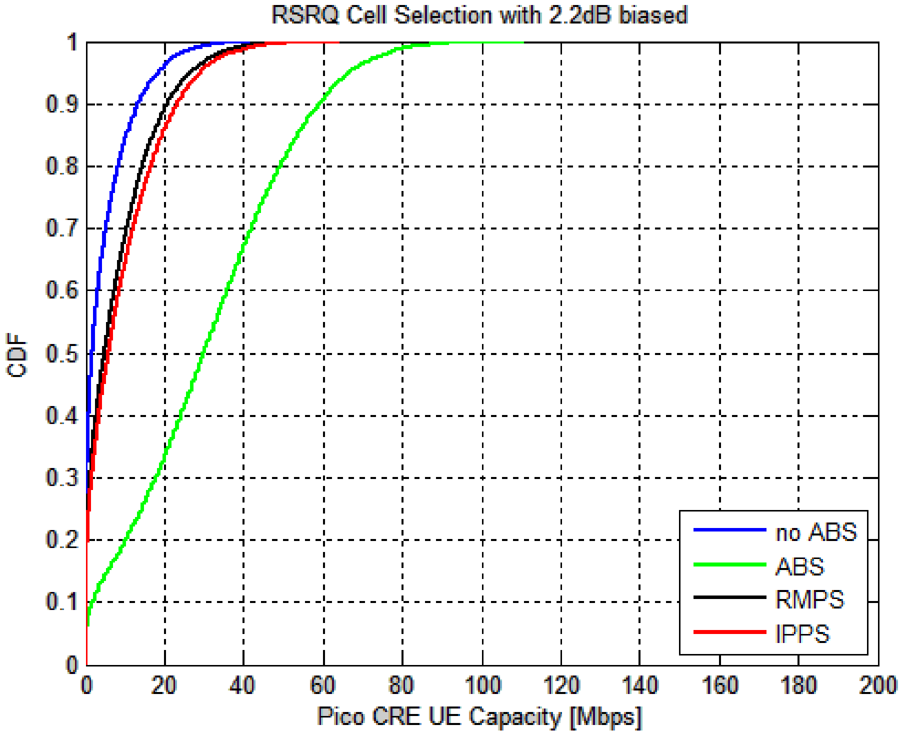

Figure 4.31. Pico CRE UE capacity for RSRQ based cell selection

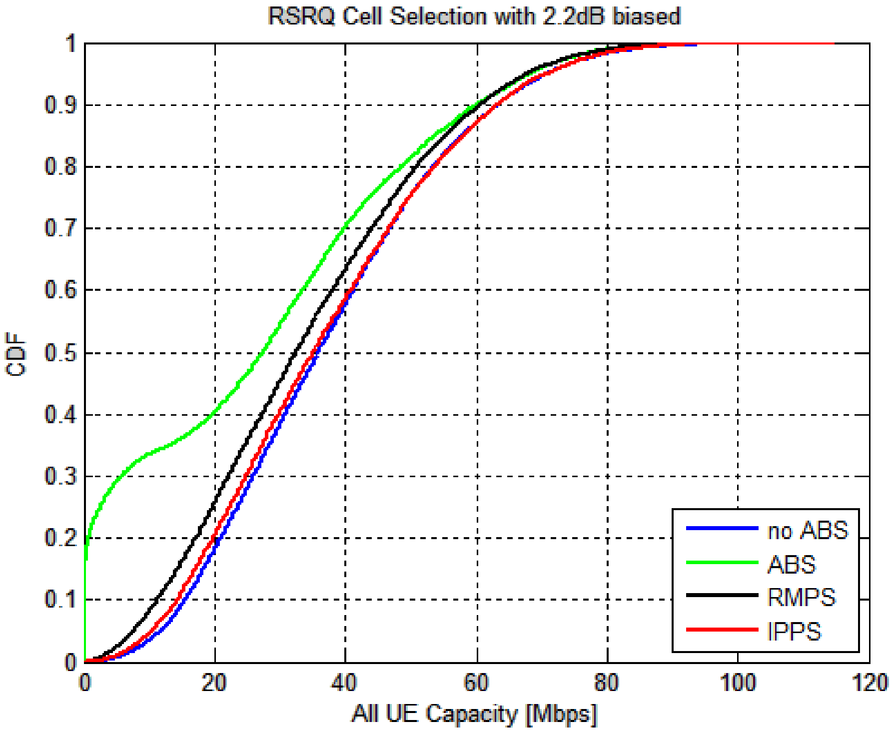

Figure 4.32. All UE capacity for RSRQ based cell selection

It can be noted that, no matter what type of cell selection method is, ABS scheme is superior in boosting the performance of CRE users. On the other hand, no ABS scheme has best macro and all UE capacity. Moreover, IPPS always outperforms RMPS.

In addition, SINR based cell selection has higher macro and all UE capacity. In contrast, RSRQ based cell selection can obtain highest CRE users capacity. It is because in RSRQ based cell selection, a big number of UEs with a higher SINR is offloaded to the pico cell compared to SINR based cell selection.

In this chapter, the cell selection methods associated with IC are investigated to observe their effect on interference management schemes in a Het-Net where pico cells overlaid on to a macro cell. Simulation results show that, for macro and all UEs no abs scheme outperforms others and for CRE UEs abs scheme shows superior performance in case of interference management. And in case of considering cell selection methods, SINR based cell selection is best for macro and all UEs and RSRQ for pico CRE UEs.

CHAPTER 5

ENERGY EFFICIENT HETEROGENEOUS NETWORKS

The swift and immense growth of the worldwide development of Information and Communication Technology (ICT) has the potential to be really a major contributor to global energy consumption which is responsible for up to 10% of the world energy consumption already in 2010. In addition, just mobile radio networks consume about 0.5% of the world energy consumption [36]. Hence, there is an authentic need for denser networks with the onward demand for broadband services, and on this behalf increased energy prices are hoped to generate a significant challenge in near future [37]. Due to some environmental aspects like lowering CO emissions and reducing energy consumption, energy efficiency recently gained huge attention. Moreover, it is necessary to assess network energy efficiency from an operator's point of view, as energy costs are raising and furnishing global high speed mobile access, which may scale up the operators' operational consumption [38]. At the earlier stage, operators have only focused on the technological developments to meet the required capacity and QoS demands of the consumers as well as mentioning the insatiate appetite for increased broadband data. Although, recent histrionic increase in energy costs requires new urgency on enhancing power efficiency in communications. Besides, in coming years energy efficiency (EE) is becoming even more significant. On the other hand, radio-frequency (RF) energy radiation from base station and mobile devices becomes a subject of concern for public health venture.

Radio access network subscribes most of the energy consumption in mobile network and has a significant impact on costs and environment. Proficient occlusion of limited network resources is climacteric in meeting the operator’s demands on cost palliation and environmental impact targets. Augmentation can be obtained in two ways.

First of all, minimizing the power consumption of the main consumer, i.e., the BS either by utilizing more power-efficient hardware or more commences software to adapt power consumption to the traffic situation as well as to parity between energy consumption and execution. The second one is, intellectual network deployment strategies where using high density deployment of LPN or base stations is considered to decrease the power consumption compared to low density deployment of high power macro base stations. The idea being that a BS closer to mobile users lowers the required transmit power due to convenient path loss conditions [39]. Hence, network deployment based on smaller cells such as micro, pico or femto cells is a feasible solution to minimize total power consumption of a cellular network. However, for designing such networks special attentions need to be approached as spreading a high consistency of small cells will cumber and decrease the power efficiency of the central BS. Besides, the embodied energy consumption may actually dominate and result in an enhancement in total energy consumption [40].

5.1. Fundamental of Energy Efficiency

5.1.1. Power Consumption Model

Generally, core network, base station and mobile terminal are the main three elements of a cellular network .Among these, base stations subscribe most of the energy consumption. While one single core network element could absorb energy up to 10 KW, the total energy absorption of core network is relatively low. This is because, the small number of core network elements compared to the base stations. Usually, power amplifier (PA) units consumes approximately 60% to 70% of base stations' energy. The energy efficiency of power amplifier depends on the required frequency band, modulation scheme and operating environment. Increasing efficiency while maintaining linearity and broadening the operating bandwidth are the main focus of the current research.

Traditional macro sites are designed to cover larger areas with a certain coverage requirement. Radiated RF power by a site, depends on the size of the covered area as well as the required degree of coverage. A linear relation between the average total power consumption and the average radiated power per site can be designed in the form below [89]:

$$P_c = \alpha . P_t + P_{fixed} \tag{5.1}$$

where P_c and P_t define the average total consumed and radiated power per site, respectively. The power consumption that measures the average radiated power due to amplifier and feeder losses as well as cooling of sites is represented by coefficient α. The term P_{fixed} defines fixed site power which is absorbed independently of the average transmit power due to signal processing as well as site cooling. α and P_{fixed} both scale with the number of sectors and the number of antennas per sector. Equation 5.1 show average power consumption as a function of the average transmits power and is suitable for both macro and pico base stations.

So, the power consumption of different BSs can be designed as the sum of two parts. One part describes the static power consumption, which is consumed by the regular operation of BS. Another part is the dynamic power consumption, which depends on the cell load.

5.1.2. Energy Efficiency (EE) Metrics

EE can be defined in various aspects according to the purpose of the system. One way is to define, as the ratio of efficient output energy to total input energy. The other way is the performance per unit energy consumption. EE metrics can be classified into two classes: absolute metrics which strike the actually energy consumed for performance and relative metrics which exhibit how EE is improved. Several metrics are used in the literatures to measure the efficiency of the communication link. Among them, the most commonly used metric is η, which is defined as the ratio of the total network throughput over the energy consumption within a given period, where the unit is bits/Joule [41].

$$\eta = \frac{R}{P_c} \tag{5.2}$$

where, R indicates the average data rate provided by a certain base station and P_c is the total power consumption. It is also possible to measure it in bit per second per watt. Though this metric is simple and instinctive, it does not count network specific aspects such as coverage and user fairness. Higher layer aspect, e.g., quality of service is also ignored here. Hence, the metric in Equation (5.2) should be complemented by other metrics. A modified metric of bit meter per joule may be used which considers the data rate as well the communication distance. It can be further modified into bits per joule per unit area for a cellular area of coverage, shown in Equation (5.10). In [44], a concept of Energy Proportionality Index (EPI) is introduced which is one of the significant energy measurements to explicate dynamic energy consumption of the equipments. It is defined by the Equation: $EMI = \frac{F-I}{F} \times 100$, where F and I both are in watts which define the maximum power consumed by a device at full load and consumed power at no load condition respectively. Energy consumption in equipment can be divided into two categories: static energy consumption and dynamic energy consumption. Static energy consumption is the energy for fostering the equipment, free from processing traffic. Dynamic energy consumption is required energy for processing traffic [44]. The energy consumption ratio (ECR) and the telecommunications energy efficiency ratio (TEER) are the two basic definitions who can explain the normalized energy metrics [45]-[47]. The ECR metric is clarified as the ratio of the peak power in Watts to the peak data throughput:

$$ECR = \frac{E}{M} = \frac{P_t T}{M} \tag{5.3}$$

where, E is the energy required to deliver M bits over time T with transmit power P_t .

This energy metric defines energy consumption in Joules consumed for conduction of one information bit. The ECR metric is evaluated either for the whole Radio Access Network (RAN) as well as for one cell or cell sector of the RAN assuming a given RF average transmission power and a given average throughput in each cell [47]. A lower ECR system is more logical in its energy use than a system with a higher ECR, since each bit demands less power for transmission [40]. The TEER metric is simpler than the ECR metric and it can be described as, useful work/power. It is possible to express the powers in dB or dBm units and modify the ECR and the TEER metrics accordingly. However, this possibility is not currently considers in the standards. Also, the standards do not clearly specify the definitions of the power used in the ECR and TEER metrics

[47].In [48], authors recently proposed an absolute energy efficiency metric, measured in dB which is given by,

$$dB_{\varepsilon} = 10\, log_{10}\left(\frac{ECR}{KT_e\; ln\, 2}\right) \tag{5.4}$$

where, K is the Boltzmann constant and T_e is the absolute temperature of medium.. Furthermore, the Energy Consumption Gain (ECG) metric has been clarified in the Green Radio (GR) project as a ratio of the ECR metrics of the two systems: a baseline reference system and a system with a more energy efficient RAN architecture. Therefore, the ECG metric computes the energy consumption elavation relative to the common reference system. In some scenarios, the Energy Reduction Gain (ERG) which is expressed in percent is more suitable. The ERG metric is derived from the ECG metric as [47]:

$$ERG(\%) = \left(1 - \frac{1}{ECG}\right) \times 100 \tag{5.5}$$

5.1.3. Area Spectral Efficiency

Conventional optimization criterion for wireless network is the area spectral efficiency. In [49], the area spectral efficiency is defined for homogeneous networks as average spectral efficiency divided by the corresponding area of a cell. The augmentation of regular heterogeneous networks is described in [50]. In [51], the area spectral efficiency is computed as the α-quantile operator (Q^{α}) of the total spectral efficiency S of a reference cell A, divided by the cell size |A|.

$$S^{\alpha} = \frac{Q^{\alpha}[S]}{|A|} \tag{5.6}$$

which is measured in bit per second per Hertz per square kilometer. Typically, a lower value of α , like 5 or 10 are estimated when focusing on fairness in the system.

Referring to the area spectral efficiency, the concept of the area power consumption for cellular networks is proposed in [52]. The metric for the area power consumption p is defined as:

$$p = \frac{P_c}{A} \tag{5.7}$$

where, P_c is the total power consumption from Equation (5.1). Area power consumption metric does not consider the provided additional network capacity and higher system spectral efficiency. So, it cannot be the exclusive metric describing energy efficiency. Nevertheless evaluating different network topologies with similar performance metrics with regard to energy efficiency can be possible by this metric [53].

5.1.4. Area Energy Efficiency (AEE)

It is well known that the cell coverage is a vital concern in the design of wireless data communications systems. And, increased inter-site distances can generate larger coverage areas. Different cell size provides different individual data rate and consequently different energy efficiency with the same transmission power. Therefore, only evaluating the energy efficiency per site is not enough for comparing networks with different cell sizes. In order to evaluate the energy efficiency of the network relative to its size, the term of area energy efficiency is introduced. It is defined as the bit /Joule/unit area supported by the cell. In general, each UE selects macro or pico station as its access node. And, each station covers different sizes of area in accordance of its transmission power and user geographical condition. Hence, the A_{EE} for a certain station can be expressed as,

$$A_{EE} = \frac{\eta}{A} \tag{5.8}$$

where, η and A respectively denote the energy efficiency in bit/Joule from Equation (5.2) and coverage area of a certain station with the unit of km^2 [41].

5.1.5. Energy Efficiency Tradeoffs

Spectral efficiency (SE) is a vastly used performance indicator for the design of 3rd Generation Partnership Project (3GPP).Which is increased from 0.05-5 bps/Hz as the system evolved from GSM to Long Term Evolution (LTE). SE oriented systems are modeled to maximize SE under peak or average power constraints. It may head to transmit the maximum allowed power for a long period of time and thus depraved from energy efficient design [54]. Energy efficiency of a communication system is not an innate fact. Information theory discloses some insights on the complication. Following Shannon formula, the SE and EE of a fading channel can be written as,

$$\eta_{SE} = \frac{R}{B} = log_2\left(1 + \frac{P}{BN_0}\right) \tag{5.9}$$

$$\eta_{EE} = \frac{R}{P_c} = \frac{B}{P}\log_2\left(1 + \frac{P}{BN_0}\right) \tag{5.10}$$

So, the relationship between SE and EE can be expressed as,

$$\eta_{EE} = \frac{\eta_{SE}}{(2^{\eta_{SE}} - 1)N_0} \tag{5.11}$$

where, P is the received power, B is the bandwidth and N_o is the noise power spectral density.

Bit per joule is the unit of the EE metric which indicates the information units transmitted per one energy unit. Equation (5.10) shows that if N_o is fixed, EE is the function of power density P/B, but the η_{EE} does not monotonically increase with B or P. In a practical system where the bandwidth is a less flexible parameter, the maximum EE of a system is hard to achieve. For a given rate R, using more bandwidth requires less power. Furthermore, the required power for infinite bandwidth is fixed to P = $N_0$1n2. This gives a hint to trade between bandwidth and energy. On the other hand, the goal to optimize rate is generally conflict with that to maximize EE. Balancing these two objectives, make the system design more complicated. Equation (5.10) gives an EE model for a generic communication system. In a wireless system, EE relies on distance, carrier frequency, and efficiency of antennas and so on. Further, interference and fading of a wireless system make alter EE following to the radio environment [54].

From Equation (5.11), η_{EE} converges to a constant 1/ ($N_0$1n2), when η_{SE} approaches zero. In contrast, η_{EE} approaches zero when η_{SE} tends to infinity. A trade-off can be found between SE and EE by exploiting the available time and frequency resources, the operation and transmit modes of the base stations. For example, if a theoretical power model is considered, i.e., the total consumed power is equal to the transmit power, the EE can be improved mainly through receive diversity in low-SE regime. Besides, the use of Multiple Input-Multiple Output (MMO) will have a large potential for improving the EE, especially in the high-SE regime [55]. Deployment efficiency (DE) is another vital network performance index for mobile operators. And, Capital Expenditure (CapEx) and Operational Expenditure (OpEx) are two elements of the deployment cost. Hence, deployment cost can define the DE to explain the effectiveness of BS deployment and the energy efficiency to evaluate the effectiveness of energy use.

The relation of DE and EE is not simple and becomes more complex when considering practical aspect. There might not always be a trade-off between DE and EE while it depends on specific deployment scenarios. But, these two facets are collaborating with each other and the design of energy efficient architecture needs a comprehensive consideration of them. Also, the energy efficiency analysis is needed to expand to the whole system, not only to the base station [58]. When the energy cost is high, the total cost is minimized for dense base station deployments while for high-density deployments, the idle power of the base stations and backhaul will become a significant factor. In addition, the energy cost is also strongly dependent on the amount of available spectrum. Significant savings in both energy and infrastructure cost can be made in total cost if more spectrum can be made available [59]. In [37] & [54], Chen identified four key trade-offs of EE with network performance; DE- EE trade-off, SE-EE trade-off, BW-power tradeoff and delay-power trade-off.

With the help of these four fundamental tradeoffs, authors demonstrated that the key network performance or cost indicators are all stringed together. To address the challenge of increasing power efficiency in future wireless networks and thereby to maintain profitability, it is crucial to consider energy efficient wireless architectures and protocols, efficient BS redesign and heterogeneous network deployment based on smaller cells.

5.2. Energy and Capacity Awareness in Het-Nets

Macro cellular network is efficient in furnishing area coverage for voice and low-speed data traffic, but narrowed in maintaining high data rates per unit area. In particular, for the cell edge users, more receiving power is required to guarantee the gracious SINR for reliable communication. Furthermore, increased number of users and demand for high data rate usage has immediate influence on energy consumption of Macro cells.

The primary way to reduce energy loss is to make the distance shorter, between a mobile unit and base station. Hence, topology specific design panoramas and enhanced planning methodologies are desirable to yield prospered power efficiency. More recent work has developed the concept of heterogeneous network, which already elaborately discussed in previous chapters. Small cells are formed in Het-Net and typically used to extend coverage where macro station signals do not reach well. It can also be used to add network capacity in areas with very dense data usage. This confirms lower path losses and propagation distances as compared to the Macro BS and hence lead to a higher SINR [61]. Moreover, as mentioned earlier that the radio access network consumes around 60% of the power consumed in the mobile telecommunications industry [62], [63]. Therefore, if it is possible to offload macro BS by low power nodes like pico and femto BSs, then Het-Net is an efficient solution to the energy, capacity and coverage issues of the current cellular system.

Many aspects might affect the energy efficiency, power consumption and the coverage area of the network. Frequency band, shadowing, path loss and the receiver sensitivity are most importantly discussed. An enquiry and exploration on energy efficiency and coverage area of macro-cell network has been done in [64]. The authors' show that the optimal cell radius and minimum transmit power is used to maintain minimum area power consumption. It can be expected from coordinated multi point transmission and reception technologies and the increased energy consumption that they induced in cellular base stations [39], [64]. The base station transmit powers are adjusted to the network density in the power pattern of their research.

Energy Aware Radio and Network Technologies (EARTH) project aims to identify concepts that will further improve the energy efficiency of wireless access networks [70]. It has been shown that the energy-efficiency optimization on system level can be significantly improved by changing the base station design along with the introduction of complementary new physical layer concepts. An appraisement framework with some augmentation which applied to quantify the energy efficiency of the downlink of a 3GPP LTE radio access network is proposed in [71]. The results disclose that, in the current network design and operation, the power consumption is voluntary of the traffic load. This clearly indicates that there is a vast potential for energy savings by improving the energy efficiency of BSs at low load. The effects of cell size on energy saving and system capacity is investigated for future mobile communication system [72].It has been shown that it is possible to establish more energy efficient, high data rate services by executing more numerous but lower powered cells in the network. In [45], work has been done in optimizing the network architecture by balancing the advantages of large and small cells. In addition, extra power saving can be gained by switching off cells with inactive users whilst maintaining the total capacity of the networks.

On the other hand in [73], Gonzalez-Brevis sought techniques to optimize the number of base stations and their locations, in order to reduce energy consumption. The inclusion of embodied energy as suggested by the authors of [40] lead to a new energy efficiency model for cellular networks. This model allows for the investigation of optimizing the number of cells and their coverage area. This model specifies that the embodied energy subscribes significantly towards the total energy consumption of the base station. Though, the model does not agree other predictors who indicate a reduction in base station power and number would lead to significant energy savings. Optimization of network architectures, with the aim of significantly reducing energy consumption, is the main focus whilst maintaining or improving the QoS. Authors demonstrated that significant energy reductions and improvements to radio transmission energy efficiency can be possible by optimizing a network's parameters with the QoS as a constraint. Some analytical tools for optimizing the

EE of a base station through power control, focusing on elastic traffic in the downlink network are provided in [75]. It reveals that the optimization problem can be composed utilizing rate maximization algorithms. In addition, with adaptive power control the near-far interference can be effectively minimized and the link signal quality can be improved. Energy per bit to noise density can be used to measure the link signal quality. Interference reduction will improve system capacity via lower energy per bit to noise density requirement and hence will attain higher energy efficiency [76]. An analytical relationship between the energy efficiency enhancements and the traffic characteristics is established in order to obtain the energy efficiency limits [77]. A first order approximation has been determined to achieve a certain amount of energy saving by selectively switching off cells [78]. In [79], authors have been developed a framework for BS energy saving that encompasses both dynamic BS operation and user association by formulating a total cost minimization problem. This shows that, depending on the arrival traffic rate and its spatial distribution as well, the energy-efficient user association and BS operation algorithms can dramatically reduce the total energy consumption by up to 70-80%.

5.2.1. Deployment of Pico Cells in terms of EE

The assignment of pico cells in cellular networks is a low power, low cost solution to obtain improved data rates for outdoor customers and parallely minimize the load of the macro cellular network. It is observed that such networks can minimize the total energy consumption up to 60% in urban area by confirming high data rate user demand. However, the massive and unplanned deployment of small cells and their uncoordinated operation may cause harmful cross-tier interference and raise important questions about energy efficiency as well in the heterogeneous cellular networks.

Clearly, there is a tradeoff relation between energy efficiency and system capacity when deploying small cells. Formation of low power nodes in wireless cellular network, may result in maximizing the system capacity in such heterogeneous networks. However, a high number of lightly loaded small cells increase the network energy consumption. Therefore, to evaluate different cell topologies for reducing the energy consumption, it is necessary to use adequate energy efficiency metrics. Different energy efficiency metrics have been introduced at the beginning of this chapter to develop the component, equipment and network level. In addition, linear models for the power consumption of different BSs are developed.

Cell energy efficiency and area energy efficiency of a two-tier network can be improved by deploying low power pico stations combined with reduction of macro transmission power [41].The evaluation performance of two-tier networks in terms of energy efficiency and fairness of resource allocation is presented in [83]. The work confirms that there exists an optimal pico-macro density ratio that maximizes the overall energy efficiency of such a two tier network. A new power consumption model considering backhaul for mobile radio network is proposed in [84]. Numerical simulation analysis shows that backhaul seems to have a large impact in three different heterogeneous network deployments: macro base stations, macro and pico base stations, macro base stations and WLAN [59].

5.2.2. Cell Selection Methods in terms of EE

Several cell selection schemes that have been discussed in chapter-3 and 4 for pico-assisted cellular networks, mostly focus on power control and cell biasing in pico base stations so as to improve user association in them. Such cell selection schemes focus only on the macro cell offloading while providing users with better bit rate. None of them consider network energy efficiency. In this sub-section an energy efficient cell selection scheme is proposed. Cell selection procedure is performed according to the following Equation:

$$u_{EE} = arg \max_{0 \leq u \leq U} \eta_{u,k} \qquad \forall k \tag{5.12}$$

where, u_{EE} represents the selected cell index based on the EE-based criteria. $\eta_{u,k}$ is the EE value of the network when user k is connected to the u-th cell, which is defined in Equation (5.2).

5.3. Performance Evaluations

A Het-Net with case-1) 6-pico nodes with orthogonal frequency allocation, case-2) single pico node with co-channel allocation and case-3) 4-pico nodes with co-channel allocation, overlaying in a macro cellular area are considered to observe the network EE. For all cases downlink operation is focused.

Table 5.1. Simulation Parameters for system energy efficiency comparison

Parameters	**Setting**
Bandwidth	10MHz
PL and shadowing models	As defined in previous Chapters
Macro cell radius	500m (case-1), 1km (case-2&3)
Max. macro BS transmit power	$P_t^{(M)} = 40$ w (46dBm)
Max. pico BS transmit power	$P_t^{(P)} = 1$w (30dBm)
EE model for macro BS	$P_{fixed}^{(M)} = 68.8$w, $\alpha_M = 3.8$
EE model for pico BS	$P_{fixed}^{(P)} = 38$w, $\alpha_P = 5.5$
Number of macro station	1
Number of pico station	Multiple
Number of UEs	40 (case-1), 500 (case-2&3)
Noise spectral density, N_0	-174dBm/Hz

Case-1:

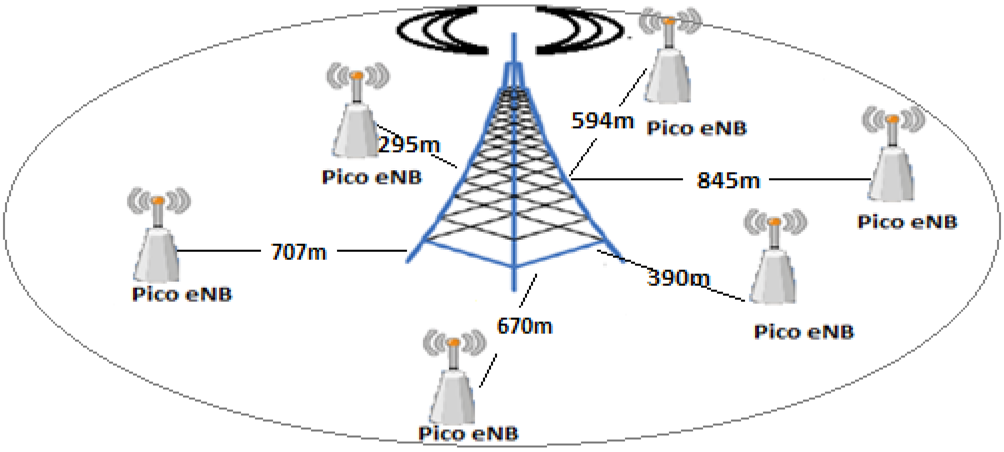

Figure 5.1. Six pico nodes in a macro cell coverage area

Figure 5.2 shows, how the network average capacity increases with the increase of pico numbers in macro coverage area. On the other hand, Figure 5.3 depicts the effect of pico numbers as well as macro transmit power on the network energy efficiency. It is noticeable that the heterogeneous network can achieve a very high EE for a reasonable numbers of pico stations.

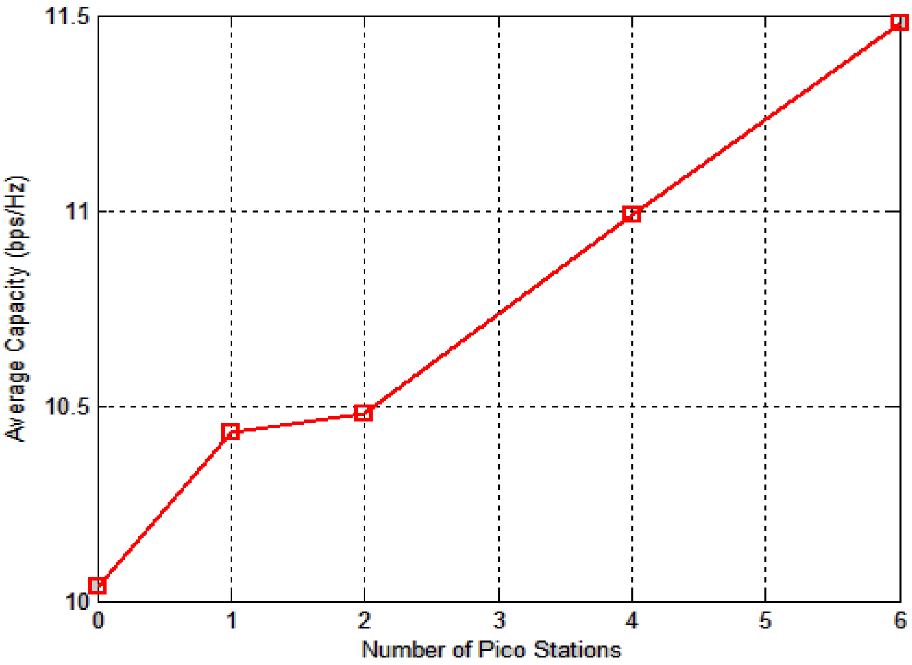

Figure 5.2. Average capacity for different number of pico nodes

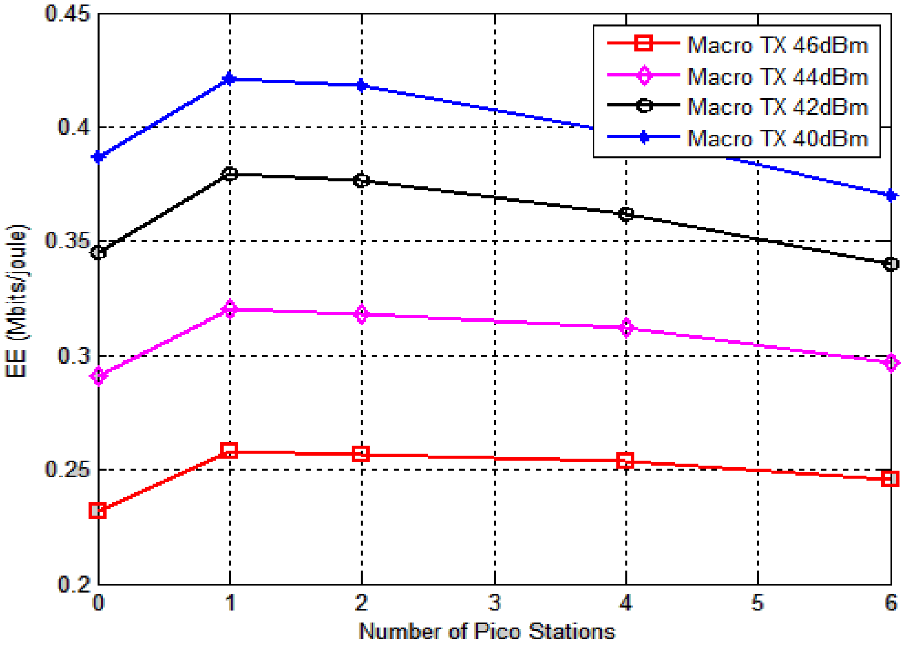

Figure 5.3. Energy efficiency comparison using RSRP based cell selection

Macro cell offloading can perform a significant impact on network energy efficiency to overcome this challenge. It can be done by applying a novel cell selection method for the system while confirming QoS constraints. Hence, EE based cell selection is proposed in this chapter which is already described in sub-section 5.2.2. Figure 5.5 and 5.7 show the performances of proposed scheme by considering case-2 and case-3.

Case-2:

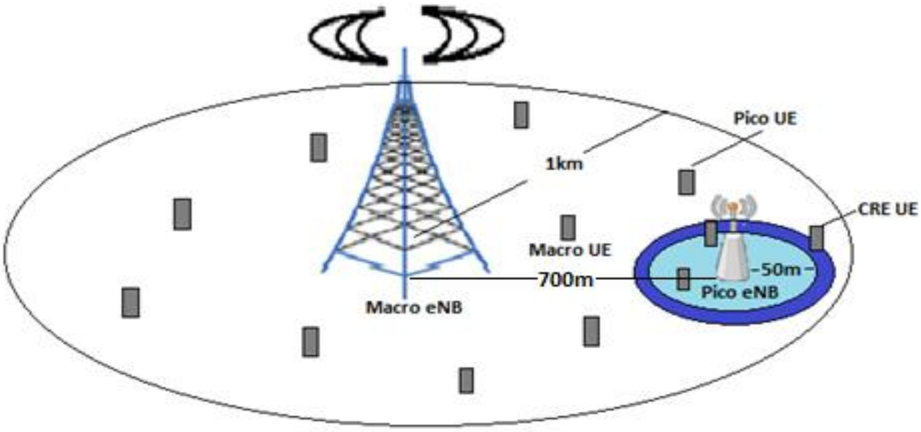

Figure 5.4. Single pico node in a macro cell coverage area

Figure 5.5 shows the impact of cell selection methods on the network energy efficiency. Increased pico power sub-frame is used as an interference coordination technique.It can be seen that the system’s energy efficiency increase slightly depending on the different cell selection schemes in conventional case. On the other hand, the proposed scheme performs noticeably better than the conventional.

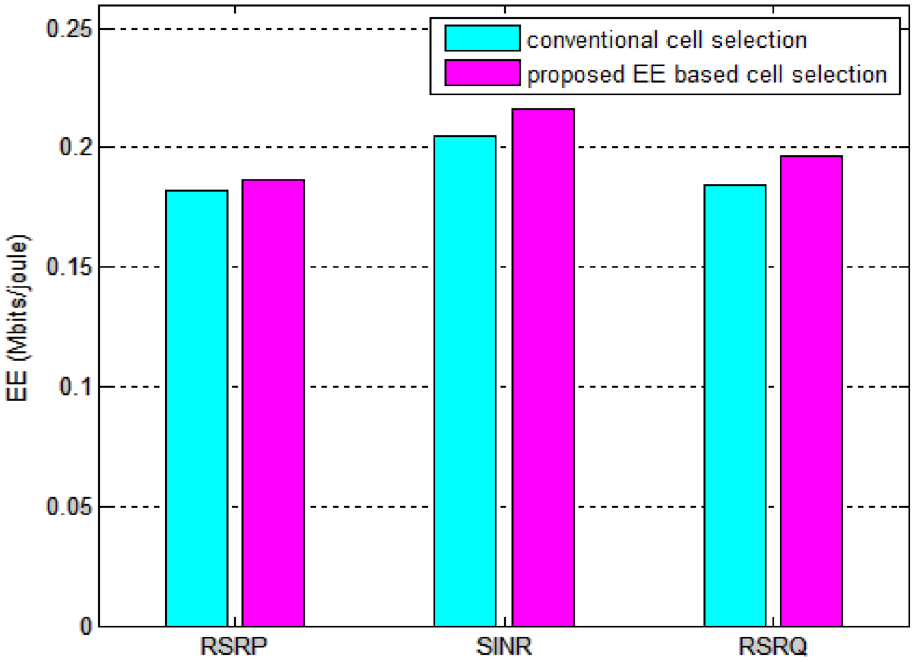

Figure 5.5. Effects of cell selection methods with IPPS interference coordination on the network EE

Case-3:

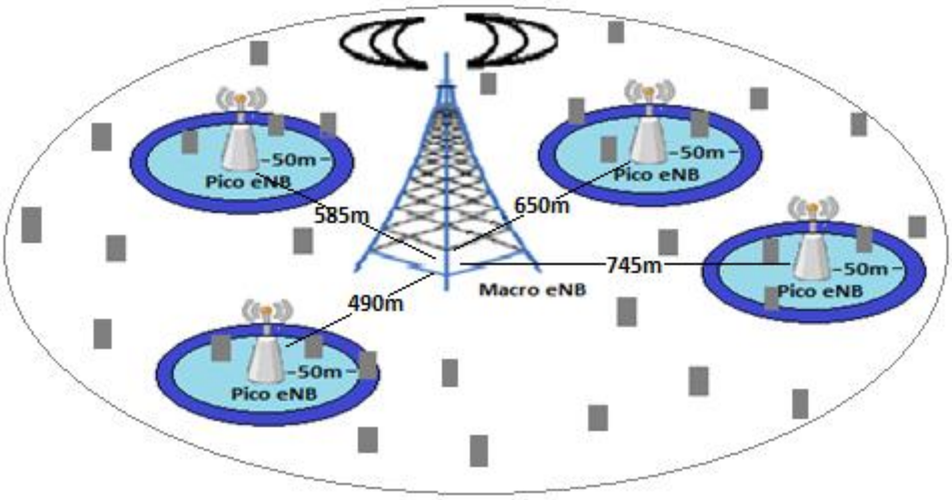

Figure 5.6. Four randomly placed pico nodes in a macro cell coverage area

Figure 5.7 depicts that, even with the higher number of pico cells, the proposed scheme lead the conventional one.

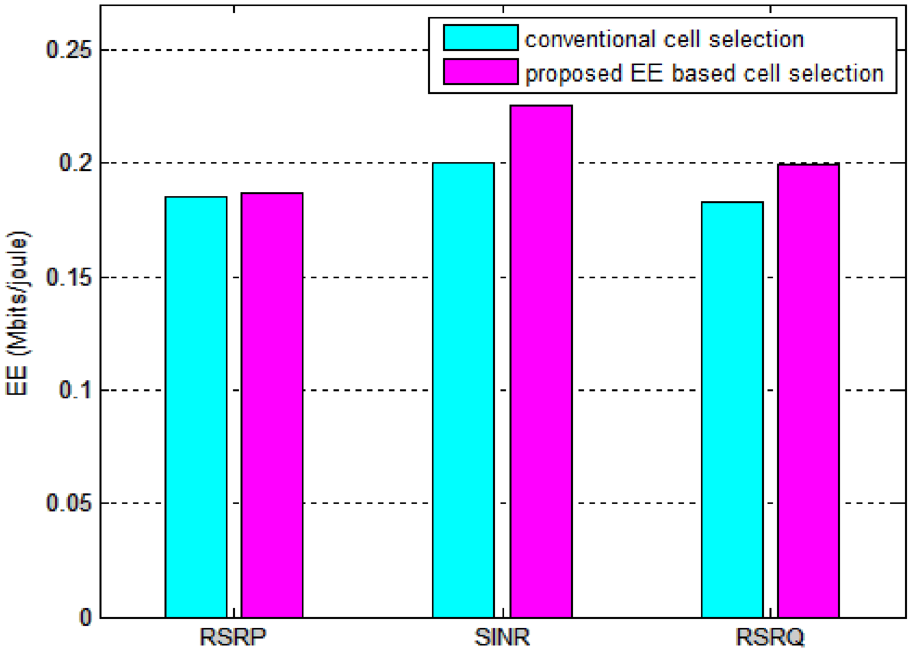

Figure 5.7. Effects of cell selection methods with IPPS interference coordination on the network EE

Due to the recent evolution of mobile communication devices, demand for network coverage and capacity is increasing exponentially. At the same time, the energy efficiency of both wireless communication devices and network attracts special attention due to the short battery life time of advanced mobile terminals and increasing operational cost of mobile networks. The Het-Net architecture is considered as a promising solution for both aforementioned capacity and energy efficiency problems. Therefore, in this chapter we summarized the challenges and opportunities to improve the EE while increasing the network capacity of heterogeneous network. Simulation results demonstrate that the proper deployment of pico cells can improve the network energy efficiency. Low power pico stations combined with reduction of macro transmission power is also beneficial. In addition, proposed EE based cell selection can enhance the network energy efficiency.

CHAPTER 6

CONCLUSIONS

In this thesis, a macro-pico heterogeneous network has been figured out as to meet next generation wireless network requirements. It is noticeable that, implementing cell range expansion is more beneficial in Het-Net deployment. The drawbacks which arise due to range expansion can be minimized by implementing different cell selection and interference coordination techniques. All results have been obtained by MATLAB.

The conclusions of this thesis can be summarized as follows:

- Macro-pico Het-Net deployment can improve the overall network performance compared to the macro only case. Furthermore, the number of pico nodes has significant affect on the network. More pico cells confirm higher network capacity, though energy efficiency has tradeoff impact.
- Different cell selection methods have different offloading effects in the network. Among them, range expansion method ensures traffic balance between macro cell and pico cell by attracting more users to pico cell, which is considered as a significant improvement of Het-Net deployments.
- Interference issues become more effective with larger range expansion bias, which leads performance deterioration scenario for cell edges users in the downlink. Hence, interference coordination through cell selection has been proposed and it is observed that, reference signal received quality based cell selection can obtain highest cell edge user's capacity.
- Different interference coordination techniques, such as almost blank sub-frame, reduced macro power sub-frame and increased pico power sub-frame have been provided an efficient solution to deal with the range expansion drawback. Almost blank sub-frame technique enhanced the cell edge and average user performance, which improves the benefits of range expansion. However, expense of macro resources and additional signaling interference issues arises in this technique. Therefore two power control techniques, reduced macro power sub-frame and increased pico power sub-frame have been examined and shown

that, increased pico power sub-frame can have good impact on the network to minimize range expansion interference without harming resources.

- When the consideration of energy efficiency of Het-Net comes, it has been provided that the network energy efficiency degrades with a higher number of pico stations. Low power pico nodes deployment with reduction of macro transmission power has been beneficial to overcome this issue. Moreover, proposed EE based cell selection has been shown performance enhancement on network energy efficiency.

Further long term investigation on heterogeneous networks, such as cell and device selection for device to device communication, self organizing network could create many opportunities to accelerate the growth of network enhancement.

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