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Energy Efficient Small Cell Planning For High Capacity Wireless Networks

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ENERGY EFFICIENT SMALL CELL PLANNING FOR HIGH CAPACITY WIRELESS NETWORKS

by

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This thesis, submitted by Md. Maruf Ahamed in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis meets the standards for appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

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3GPP	3rd Generation Partnership Project
DL	Downlink
HSPA	High Speed Packet Access
LOS	Line of Sight
LTE	Long Term Evolution
MIMO	Multiple-Input and Multiple-Output
SINR	Signal to Interference plus Noise Ratio
SMS	Short Message Service
UE	User Equipment
UL	Uplink
BS	Cellular Base Station
QoS	Quality of Service
CoMP	Coordinated multi point transmission
eCoMP	Enhanced Coordinated Multi Point Transmission
CA	Carrier aggregation
FDD	Frequency Division Duplex
TDD	Time Division Duplex
ASA	Authorized shared access
Tx	Transmitter

Rx	Receiver
CSG	Closed subscriber group
DSL	Digital subscriber lines
SON	Self-organizing network
DSL	Digital Subscriber Line
HetNet	Heterogeneous Networks
RSRQ	Reference Signal Received Quality
RSSI	Received signal strength indicator
TAI	Tracking area indicator
RSL	Received signal level
RLB	Radio Link Budget
eNodeB	E-UTRAN Node B
OFDMA	Orthogonal Frequency-Division Multiple Access
QPSK	Quadrature Phase-Shift Keying
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
SC	Small Cell
eICIC	Enhanced inter-cell interference coordination
ICIC	Inter-cell interference coordination
CRE	Cell range expansion
ABS	Almost blank sub frames
C/I	Carrier-to-interference ratio
RSRP	Reference signal received power

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To my family.

ABSTRACT

This thesis presents a new strategy to densify Small Cells (i.e., add more low powered base stations within macro networks) and enhance the coverage and capacity of Heterogeneous Networks. This is accomplished by designing Micro Cell for outdoor applications, Pico and Femtocell for indoor applications. It is shown that, there exists a free space propagation medium in all propagation environments due to Fresnel zones, and the path loss slope within this zone is similar to free space propagation medium. This forms the basis of our development of the present work. The salient feature of the proposed work has two main considerations (a) The cell radius of Small Cells must be within the first Fresnel zone break point, and (b) The minimum inter-cell distance must be greater than twice of Small Cell radius.

The proposed network is simulated in real a radio network simulator called ATOLL. The simulation results showed that densify Small Cells not only enhanced the capacity and coverage of Heterogeneous Networks but also improved the carrier to interference ratio significantly. Since the proposed work allows UE (user equipment) to have Line of Sight (LOS) communication with the serving cell, and UE can have higher uplink (UL) signal to interference plus noise ratio (SINR) that will further allow UE to reduce its transmission power, which will consequently lead to a longer battery life for the UE and reduce the interference in the system.

CHAPTER 1

INTRODUCTION

According to recent projections, mobile data traffic is getting doubled every year and the estimated increase roughly by a factor of 1000 in the next 10 years [1]. This increasing capacity requires fundamental changes in cellular network planning and deployment [2]. Hence, the service providers need to add more capacity with significantly lower cost per bit. New ways to enhance the revenue are also of interest to the service providers [3].

There are three main approaches to cope this data demand: (i) network densification: by deployment of Small Cells, (ii) adding more bandwidth: wider bandwidth that is realistic at millimeter wave frequencies, and (iii) improving spectral efficiency: by using advanced radio access technology, such as Long Term Evolution (LTE), and utilizing special features like massive-multiple-input and multiple-output (MIMO), and better interference management techniques. The last two approaches are certainly important pieces of the puzzle [4], the most of the gains can be achieved by network densification.

This thesis presents different deployment scenarios of Small Cells and propose a method to deploy Small Cells densely within or outside of macro layer and enhance the coverage and capacity of heterogeneous networks.

It is shown that, there exists a free space propagation medium in all propagation environments due to Fresnel zones, that the path loss slope within this zone is similar to that of free space propagation medium. The salient feature of the proposed work has two main considerations (a) the cell radius of Small Cells must be within the first Fresnel zone break point, and (b) the minimum inter-cell distance must be greater than twice of Small Cell radius.

This thesis also investigates mobility management problems in Heterogeneous Networks and propose a new cell selection scheme called path loss slope based cell selection, where a UE (user equipment) selects the best cell based on the path loss slope value of the received signal instead of the received signal level. The performance of the proposed cell selection scheme is also shown and compared with conventional cell selection schemes. Finally, it is proved that, conventional cell selection schemes are no longer sufficient when Small Cells are densely deployed for indoor or outdoor scenarios.

This thesis is organized as follows. Chapter 2 represents the motivation to deploy Small Cells and brief overview of Small Cell networks. Different deployment scenarios of Small Cells are discussed in chapter 3.The proposed Small Cell architecture is also proposed in this chapter. In chapter 4 different cell selection methods are discussed and a new cell selection method based on the path loss slope value of received signal is proposed. In addition, coverage and capacity planning are discussed in chapter 5 and interference in Small Cell networks are discussed in chapter 6. Finally simulation and results are shown in chapter 7. In chapter 8, some conclusions are drawn.

CHAPTER 2

SMALL CELL NETWORKS OVERVIEW

2.1 Motivation to Deploy Small Cells

Until 2010, cellular network was planned to support voice calls and Short Message Service (SMS). The reliable delivery of 15 kbps or so was enough to keep an end user happy. But the game has changed in the last few years due to the rapid growth of mobile broadband traffic, driven by the growing adoption of the data hungry multimedia services. Since the popularity of connecting devices (e.g., smartphones and tablets) has increased, the data-rate demands per user has increased dramatically [5]. According to recent projections, mobile data traffic is getting doubled every year and the estimated increase of 1000 times in the next 10 years [6, 7]. Hence, the service providers need to add more capacity with significantly lower cost per bit and finding some ways to enhance the revenue as well [7]. There are several approaches to meet this traffic demand, shown in Figure 1. The Traditional approaches are explained in the following [8, 9]:

2.1.1 Enhance Macro Layer Efficiency

Improving the existing Macro Network can be a possible way to enhance the capacity of macro network. This can be done by using advanced radio access technologies or by adding more spectrums in the macro networks, as discussed below.

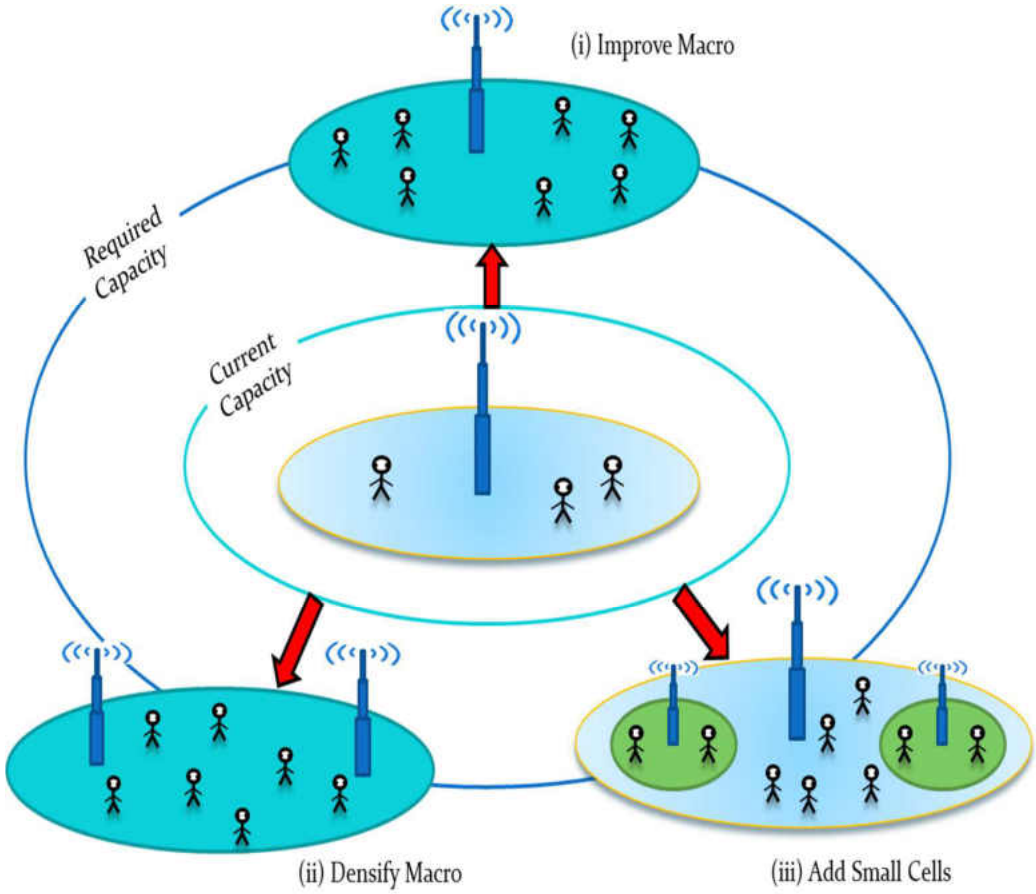

Figure 1. Approaches to enhance the capacity of cellular networks

2.1.1.1 Advance radio access technologies. The continued evolution of High Speed Packet Access (HSPA) and Long Term Evolution (LTE) technology increases the network efficiency [3]. The operators can achieve the full potential of LTE networks by upgrading the following three key technologies

a) ***Multiple-Input Multiple Outputs (MIMO).*** MIMO refers to the idea where cellular base stations (BSs) can equip a very large number of antennas that allows significant improvement of spectral and energy efficiency using relatively simple (e.g. Linear) processing [10, 11]. MIMO and advanced receivers can add capacity gain up to 100% in the cell edge and up to 30% in cell center [12]. MIMO implemented using diversity techniques that provide diversity gain and improves the system reliability. In addition, massive MIMO (also known as a large scale antenna system, very large MIMO, and hyper MIMO) brings huge improvements in throughput and radiated energy efficiency.

b) ***Smart scheduling.*** In case of conventional LTE schedulers, radio resources are allocated to active subscribers in each cell, hence substantial spectrum remains unallocated. On the other hand, smart scheduler assigns spectrum blocks to users in every millisecond based on their application demands and required quality of service (QoS). Smart scheduling can mitigates inter-cell interference and improve cell capacity by more than 20%. It can also boost cell edge data rates by more than 100% and can achieve more than 50% average throughput than conventional LTE schedulers [3].

c) ***Coordinated multi point transmission (CoMP).*** In a distributed network architecture (e.g., LTE Release 8), data are transmitted to the mobile device from one cell at a time [14]. But, CoMP is a facility of LTE advanced networks, where multiple cells can transmit data to a single mobile device [15]. By providing connections to multiple base stations at a time, data can be passed to the least loaded base stations to enhance resource utilization. The overall reception can also be improved by using several cell sites for each connection, hence, the number of dropped calls is reduced. In addition, specialized combining techniques allow utilizing the interference constructively, instead of destructively, thereby interference is reduced. Further improvement can be achieved by using enhanced Coordinated Multi Point Transmission (eCoMP), which allows multi-cell resource control [13].

2.1.1.2 New spectrum and optimal use of spectrum. Maximizing the utilization of existing spectrum or adding more spectrums into services can add more capacity in the macro networks. There are three strategies to improve as follows:

a). ***Carrier aggregation.*** Carrier aggregation is one of the most distinct features of LTE Advanced, which is being standardized by 3rd Generation Partnership Project (3GPP) [17]. This feature allows scalable expansion of effective bandwidth delivered to a user through simultaneous utilization of radio resources across multiple carriers. This can be done by aggregating several smaller contiguous or non-contiguous carriers [16]. For instance, a 100 MHz system can be constructed using contiguous or non-contiguous 5×20 MHz. Carrier aggregation is supported by the Frequency Division Duplex (FDD) and Time Division Duplex (TDD) both and it guarantees to meet the high data throughput required by each of them.

b). ***Deploy new spectrum.*** Operators are able to use the 700, 800, 900, 1800, 2100 and 2600 MHz bands (EU example) for LTE networks and HSPA capacity upgrades by the next few years. Capacity gain is possible by integrating use of TDD and FDD spectrum. For instance, unused TDD spectrum will initially supplement downlink or uplink FDD capacity, and then efficient carrier aggregation across technologies will further bridge local and wide area assets.

c). ***Authorized Shared Access (ASA).*** ASA is a regulatory approach for sharing bands where usage is low, but not vacated fully by incumbent users [16]. ASA balances the mobile network operators with those needs of legacy spectrum users and enables the availability and licensed use spectrum with QoS.

2.1.2 Densifying the Macro Network

The second possible solution is to densify the macro network. A simple way to densify the macro network could be adding more sectors per Macro Cells. Splitting cells horizontally can create additional sectors. For instance, upgrading a three sector site into a six-sector site can boost capacity by up to 80% and the coverage of up to 40%. Vertical splitting is also possible by deploying active antennas for beamforming. Two independent dynamic beamforming can deliver up to 65% more capacity, as well as better coverage with high data rates. Another way to densify the macro network would be deploying more Macro Cells within the networks.

However, reducing the inter-cell distance and adding more Macro Cell in the network can only be pursued in a certain extent because finding a position for new Macro Cells becomes increasingly difficult and expensive, especially in the city centers. Besides, the number of handoff within a cell will increase due to more Macro Cells in the vicinity and additional software will need for this handoff.

2.2 Introducing Small Cell Networks

Small Cells are radio access nodes that can operate in licensed and unlicensed spectrum and are operated by low-power. These nodes are "too small" compared to a traditional Macro Cell, they are named Small Cells. The typical radius of a Small Cell will be less a kilometers, whereas a Macro Cell can have a range of a few tens of kilometers.

The most promising approach to meet high capacity demand is to add more Small Cells within the macro network and distribute the traffic between Macro Cell and Small Cell [18]. Data capacity of a cell is defined as the aggregated cell throughput per cell. With the identical condition (e.g. same channel bandwidth), the aggregated cell throughput of a cell will remain the same, regardless of the size of the cell. Therefore, the aggregated cell throughput for Macro Cell, Micro Cell, Small Cell, and Femtocell are the same. This means that the total capacity is inversely proportional to the square of the cell radius. For instance, if the cell radius is reduced to half, the cell capacity will be quadrupled.

The cell capacity is a function of several variables such as user distribution, fading characteristics, and traffic moving speed. Small Cell users are slowly moving and usually are located closer to the cell center with less fading, so the aggregated cell throughput from a Small Cell is higher than a Macro Cell. Thus, by splitting the traffic from one large cell into multiple Small Cells, the actual achieved capacity gain will be higher than the square law [17].

2.3 Types of Small Cells

According to the cell radius and transmit (Tx) power levels, wireless cells can be categorized into Macro Cells, Micro Cells, Pico Cells, and Femtocells [5]. The actual cell size does not only depends on the cell Tx power, but also depends on the position of the antenna, antenna height, as well as the deployment environment, e.g. indoor or outdoor, rural or urban environment [6]. Any of the cells can be a better candidate than others depending on different deployment environments, the type of communications, and the quality of services. Table 1 shows the different types of Small Cells with corresponding cell radii and Tx power levels [7].

Table 1. Small Cell Types

Cell Type	Cell Radius	PA Power Rang & Typical Value	Number of UEs	Developed by	Managed by
Macro	>1Km	20W-160W (40W)	1200	Operator	Operator
Micro	250m–1Km	2W-20W (5W)	400	Operator	Operator
Pico	100m-300m	250mW~2W	64-256	Operator	Operator
Femto	10m-50m	10mW-200mW	10-50	Consumer	Consumer

2.3.1 Macro Cells/ Micro Cells

In current cellular networks, Macro Cells are deployed by operators for wide area coverage and the coverage footprint varies for different traffic conditions. The typical inter-site distance for Macro Cells are more than 500m in rural or suburban areas, while Micro Cells are deployed in urban areas with smaller cell radius. In heterogeneous networks, large Macro Cells hold advantages to support high mobility users and reduced handover frequency [6].

2.3.2 Pico Cells

Pico Cells are deployed by the operator for smaller area coverage compared to Micro Cells. It can be deployed in outdoor public venues and hotspots, especially in capacity starved locations like stadiums, airports, and shopping malls [5]. The deployments of Pico Cells are carefully planned by the operators, and are open and accessible by all cellular users. Since, Pico Cells use lower Tx power than Micro Cells, it has reduced the transmission cost [6].

2.3.3 Femtocells

Femtocells are usually privately owned unlike Micro Cells or Pico Cells and can be deployed more efficiently based on user's needs. A Femtocell covers even small areas (10-50m), such as a house or an apartment [5]. Since Femtocells can connect to the network by existing residential backhaul links such as cables or Digital Subscriber Lines (DSL), it can save infrastructural cost [6]. Typically, Femtocells are under Closed Subscriber Group (CSG) operation, where only specific users are allowed to access the network through Femtocells [7]. This may cause interference to the network when sharing the same spectrum with other tiers.

2.4 Small Cell Networks Deployment Challenges

Small Cells can be installed by subscribers, unlike traditional macro network installed by operators [8, 9]. Thus, it introduces a significant network paradigm shift from traditional centralized network to unplanned and uncoordinated network approaches. These changes can be seen as a good approach for enhanced, however, they also entail some technical challenges [5, 9]. The key deployment challenges of Small Cell networks are discussed in this section.

2.4.1 Backhauling

Backhaul solution is needed for a network with large number of Small Cell sites. Backhaul can be supported by a physical transmission medium, including microwave, optical fiber, laser, copper lines, and wireless connectivity. Backhauling affects the data throughput available for users, thus it affects the overall performance of the networks [5]. However, for more tight coordination's of Small Cells and optimized uses of available spectrum, a high performance backhaul with low latency is needed.

Since various types of cells can coexist in Small Cell networks, backhauling will be a major issue to maintain the overall performance of the networks [5]. For instance, Pico Cells require access to utility infrastructure with power supply and wired network backhauling, which may be expensive [8]. On the other hand, Femtocell can use consumer's broadband connections for backhauling. This reduces dedicated backhauling cost. But it may face difficulties to maintain quality of service (QoS) [9]. The operators need to plan backhaul solution carefully to minimize the backhauling cost and also guarantee the quality of service of the networks.

2.4.2 Handover

Handovers and mobility management are necessary in order to provide seamless uniform services when users are moving around the different cell coverage [5]. Besides, handovers are efficient to offload the traffic from highly congested cells to the less congested neighbor cells [9]. In Small Cell networks, as the density of Small Cells increase, the probability of handover increases. It is a challenge for Small Cell networks to reduce signaling load to the core network and optimize handover performance. Small Cell networks needed careful planning of handover parameters, which probably is different from the traditional Macro Cells.

2.4.3 Self-Organizing Networks

One of the key features of the Small Cell networks is that users or operators can deploy Small Cells without careful network planning [9]. The operators may not configure individual Small Cells, but Radio Frequency (RF) environment will vary continuously after Small Cells deployment. Hence each Small Cell needs to be monitored continuously for any changes of the RF environment and reconfigure it if needed. Self-Organizing Network (SON) possess an automated operation in cellular networks, and uses automated and intelligent procedures to replace human intervention in the networks without compromising the network performances. The key features of SONs can be categorized by the following three processes [9, 19]:

a) ***Self-configuration:*** Newly deployed cells are automatically configured by the software before the cells enter in the operational mode.

b) ***Self-healing:*** Cells can automatically perform failure recovery or execute compensation mechanism whenever a failure occurs.

c) ***Self-optimization:*** Cells can continuously monitor the network status and can optimize the network settings for better coverage and less interference scenarios.

2.4.4 Interference

Unlike traditional single tier cellular networks, in heterogeneous networks, Small Cells overly Macro Cells and originate new cell-boundaries, in which end users may suffer strong inter-cell interference. In addition, different backhaul link solution with different bandwidth and delay constraint for each cell may add more challenges for interference coordination [9]. For instance, Pico Cells use X2 interface for exchanging signals, whereas Femtocells use internet connection Digital Subscriber Line (DSL), thus delay issues may appear [10]. The main reasons that cause interference in Small Cell networks and different interference coordination methods are discussed in Chapter 6.

CHAPTER 3

DENSE SMALLC ELL DEPLOYMENT

3.1 Introduction

Innovative upgrades and new technology will significantly enhance the Macro Cellular network capacity. Once Macro Cells reach their limits, Heterogeneous Networks will be the norm to meet the high traffic demand. It is expected that more than 30 percent of the world population will live in metro and urban areas by 2017. Although these areas represent less than one percent of the Earth's total land area, they will be the source of around 60 percent of mobile traffic by 2017 [1]. Macro Cells are the proven cost effective solution, but it will be increasingly challenging to meet the traffic demand in the following scenarios, such as [2];

a). Large outdoor hotspots, such as commercial streets and town squares. If these areas are already served by a dense macro network but still there is a high growing traffic demand. The interference will also be high in those areas.

b). Large, isolated indoor hotspots, such as hotels and businesses. It will be difficult to meet capacity and maintain the quality of service of the network.

c). Large indoor hotspots, such as airports, shopping malls, and subway stations, where interference and mobility demands are high.

d). Localized indoor hotspots or minor coverage holes, such as retail outlets, small offices, and restaurants. The deployment challenge will be the cost structure of conventional cellular networks

In those outline scenarios; Small Cell networks will be a better solution than macro network improvements, to maintain high quality user experience and provide good coverage as well. Ericsson expects that each Macro Cell will on average have three supporting Small Cells in metro and urban areas by 2017 [2].

3.2 Small Cell Deployment Scenario

Until LTE Release 12, the Small Cell deployments are considered in sparse co-channel scenarios, but LTE Release 12 focuses mostly on dense Small Cell deployments operating on separate carriers to the Macro Cell. The proposed work and simulation are based on this scenario. Three deployment scenarios have been identified in LTE Release 12, (1) Small Cell deployed in the same carrier F1 as the Macro Cell, (2) Small Cell deployed in carrier F2 different from the Macro Cell carrier F1, and (3) Standalone deployment of Small Cells, as shown in Figures 2, 3 and 4 [6, 8, 20, 21, 22].

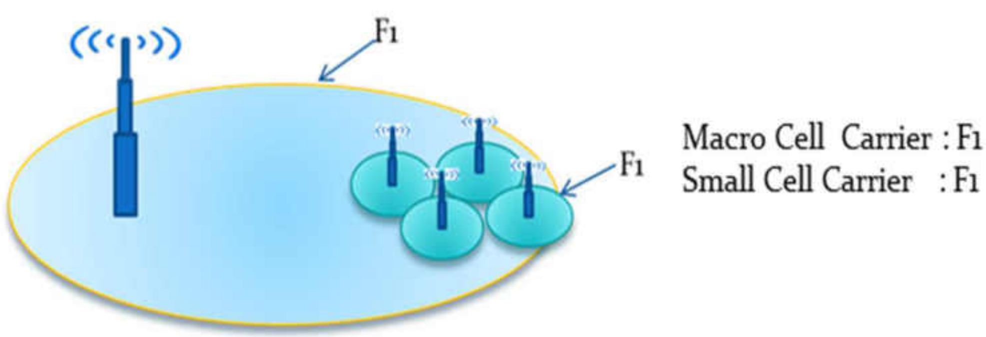

Figure 2. Co-channel Deployment (same carrier frequency for Macro Cell and Small Cell)

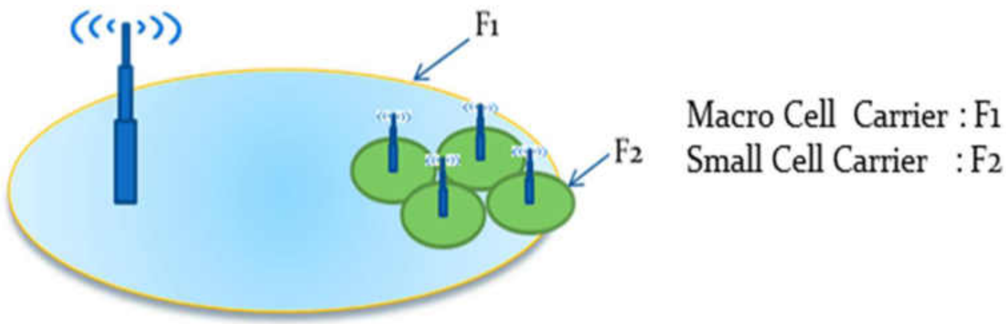

Figure 3. Dedicated-channel deployment (different carrier frequency for Macro Cell and Small Cell)

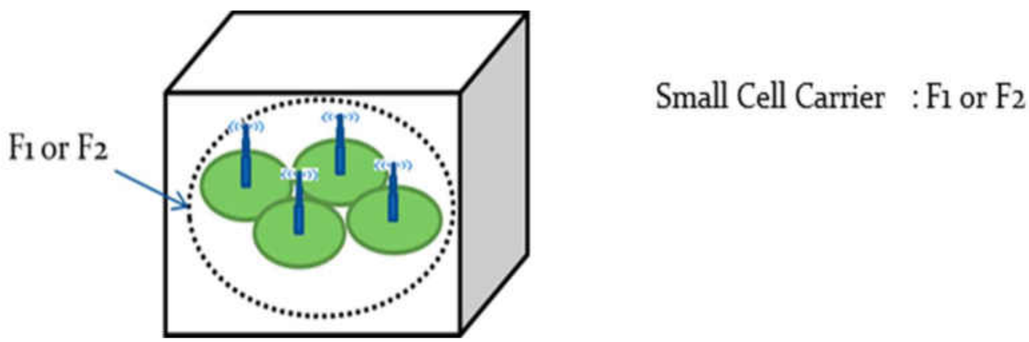

Figure 4. Standalone Small Cell clusters (no coordination with Macro Cell)

3.3 Proposed Small Cell Architecture

3.3.1 Overview of Fresnel Zone Effect

When any wave-front encounters an obstacle it bends around the objects and spread out when passing it through a gap. This phenomenon is known as diffraction [23]. Likewise, diffraction of radio waves occurs in multipath environment when the radio waves encounter any obstacles [24]. This can be examined by a model developed by Augustin-Jean Fresnel for optics [25]. Fresnel postulated that the cross-section of any optical wavefront (electromagnetic wavefront) is divided into zones of concentric circles separated by $\lambda/2$ (Figure 5), where λ is the wavelength.

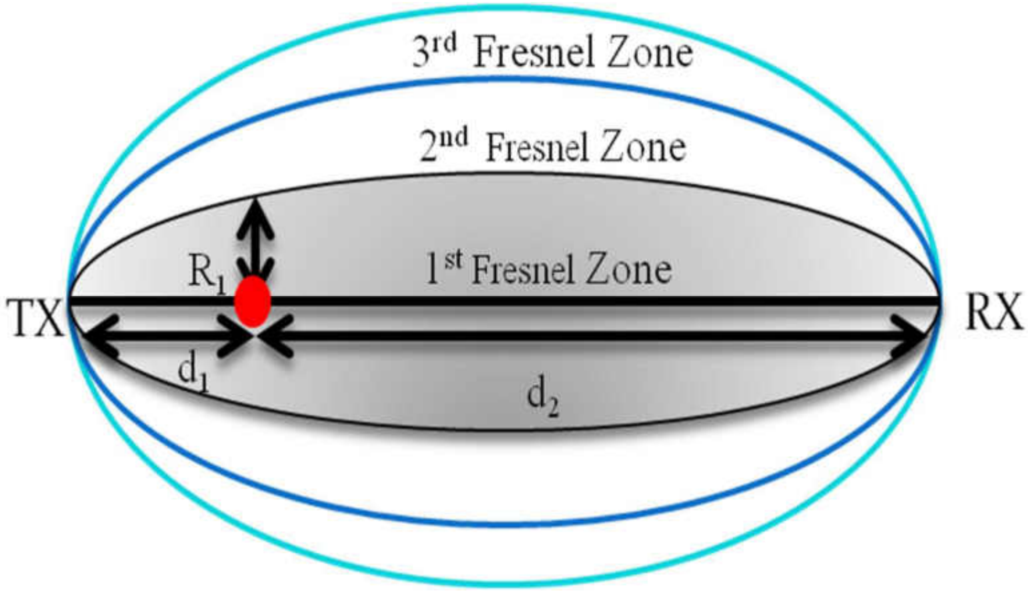

Figure 5. The Fresnel zones

The radius of the nth Fresnel zone is given by

$$R_n = \sqrt{n\lambda \frac{d_1 d_2}{d_1 + d_2}} \tag{3.1}$$

Where, d1 is the distance between the transmitter and the obstruction, d2 is the distance between the receiver and the obstruction, λ is the wavelength is equal to c/f where c is velocity of light and f is the frequency, n = 1 for the first Fresnel zone, and n = 2 for the second Fresnel zone.

Equation (3.1) indicates that the Fresnel zone radius is inversely proportional to the square root of frequency. Thus, for a given antenna height, a high frequency signal will propagate further before the first Fresnel zone touches the ground. Similarly, for a given frequency, a signal that radiates from a tall antenna will propagate further before the first Fresnel zone touches the ground. In short, diffraction of radio waves depends on frequency as well as on antenna height. The maximum diffraction occurs when the path difference between the direct ray and diffracted ray is λ/2. This can be verified by two-ray model, show in below Figure 6.

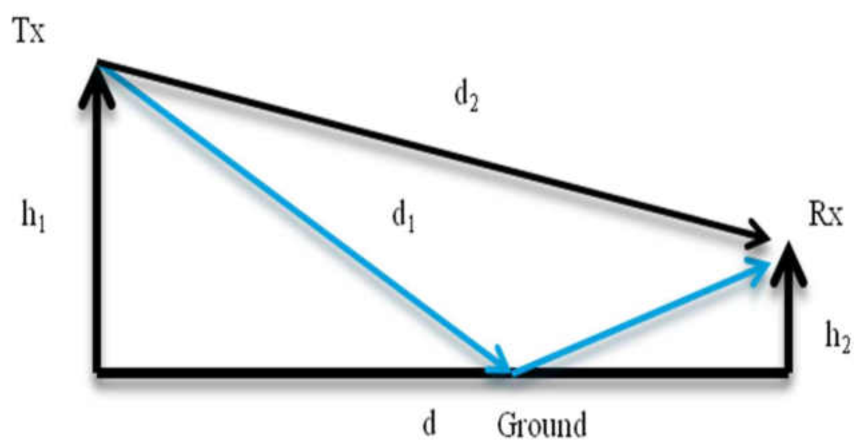

Figure 6. Two ray propagation model

In Figure 6, h1 is the transmit (Tx) antenna height, h2 is the receive (Rx) antenna height, d is the antenna separation, d1 is the length of reflected path, d2 is the length of direct path. The path difference between direct and reflected path can be found according to plane geometry as

$$\Delta d = \sqrt{(h_1 + h_2)^2 + d^2} - \sqrt{(h_1 - h_2)^2 + d^2} \qquad (3.2)$$

Where, $\Delta d = d_2 - d_1$. Equation (3.2) can be further rewritten as

$$\Delta d = \frac{4h_1 h_2}{d\sqrt{(\frac{h_1 + h_2}{d})^2 + 1} + d\sqrt{(\frac{h_1 - h_2}{d})^2 + 1}} \qquad (3.3)$$

Where (h1 ± h2)/d << 1, the path difference in the equation (3.3) reduces to

$$\Delta d \neq 2\frac{h_1 h_2}{d} \tag{3.4}$$

Now the composite received can be expressed as

$$P_r = P_T(\frac{\lambda}{4\pi d})^2[1+e^{j\Delta\theta}]^2 = P_T(\frac{\lambda}{4\pi d})^2[4\sin^2(\frac{\Delta\theta}{2})] \tag{3.5}$$

Where, P_T is the power of the transmitted signal, P_r is the composite received power and $\Delta\theta$ is the phase difference between the direct and the reflected path. In terms of path difference $\Delta\theta$ is given by

$$\Delta\theta = (\frac{2\pi}{\lambda})\Delta d \tag{3.6}$$

Thus equation (3. 5) can rewrite with the new value of $\Delta\theta$ as

$$P_r = P_T(\frac{\lambda}{4\pi d})^2 \times [4\sin^2(\frac{\pi}{\lambda})\Delta d] \tag{3.7}$$

Further equation (3.7) can be rewrite by putting the value of Δd from the equation (3.4) as

$$P_r = P_T(\frac{\lambda}{4\pi d})^2 \times [4\sin^2\{(\frac{\pi}{\lambda})\times 2\frac{h_1 h_2}{d}\}] \tag{3.8}$$

P_r will be maximum when $\sin^2\{(\pi/\lambda)\times 2h_1h_2/d\}$ is maximized. Thus,

$$\frac{\pi}{\lambda}\times 2\frac{h_1 h_2}{d} = \frac{\pi}{2} \tag{3.9}$$

Or

$$d_0 = d = 4\frac{h_1 h_2}{\lambda} \tag{3.10}$$

Note that d is now replaced by d_0 and this distance is known as Fresnel zone break point which is proportional to antenna height and frequency. Therefore, it can conclude that path loss characteristic within d_0 will be similar to free space path loss due to maximum diffraction. But the signal attenuates faster beyond d_0 due to destructive multipath components which varies according to different propagation environment such as rural, suburban, urban, and dense urban, shown in Figure 7.

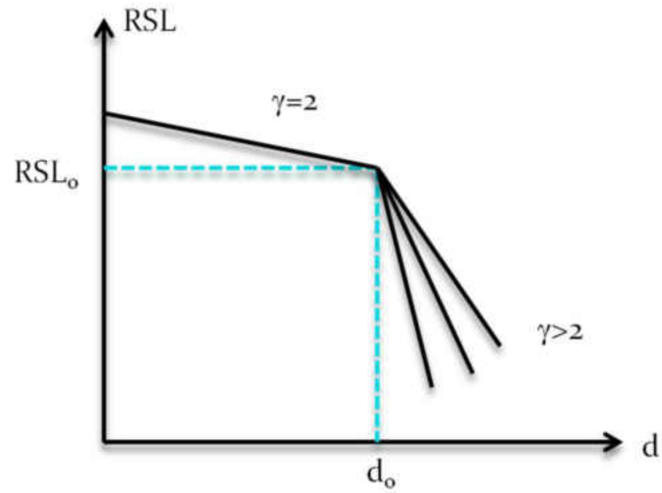

Figure 7. RSL (signal strength) over distance with different attenuation slope

In the following Figure 6, γ is the attenuation slope and the value of attenuation slope varies between 3.5 and 4 for a typical and dense urban environment [10]. Whereas, RSL is received signal level in dBm, RSL_0 is received signal level at the Fresnel zone breakpoint d0, and d is the range at the desired RSL.

3.3.2 Proposed Small Cell Architecture

According to Figure 6, signal strength attenuates more slowly before reaching the break point d_0, and it attenuates faster after the breakpoint. In the proposed Small Cell architecture, the radius of Small Cell (R) is consider to be less than or equal to the first Fresnel zone break point (B). In addition, inter-cell distance (D) is slightly more than twice of Small Cell radius (R) (Figure 8), so that the in-cell signal level have a slow attenuation slope (γ=2) but out-of-cell signal level have a faster attenuation slope (γ>2).

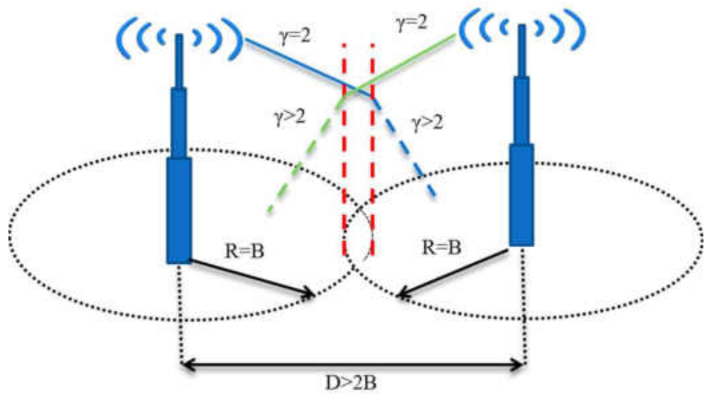

Figure 8. Proposed Small Cell architecture

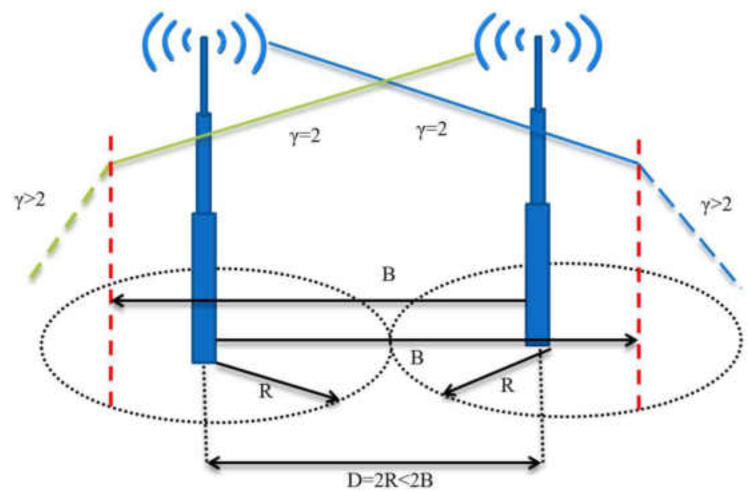

Figure 9. Inter-cell distance too small, undesirable

If two Small Cells are placed too close to each other, then the out-of-cell interference will not attenuate fast enough, thus overall signal to interference ratio degrade and the proper cell selection will not succeed, as shown in Figure 9.

Total out-of-cell interference can be found by adding interferences coordinated from all neighbor cells, as shown in Figure 10. Total out-of-cell interference = ∑ (Interference coordinated from the first-tier neighbors + Interference coordinated from the second-tier neighbors + ……+ (Interference coordinated from the kth - tier neighbors).

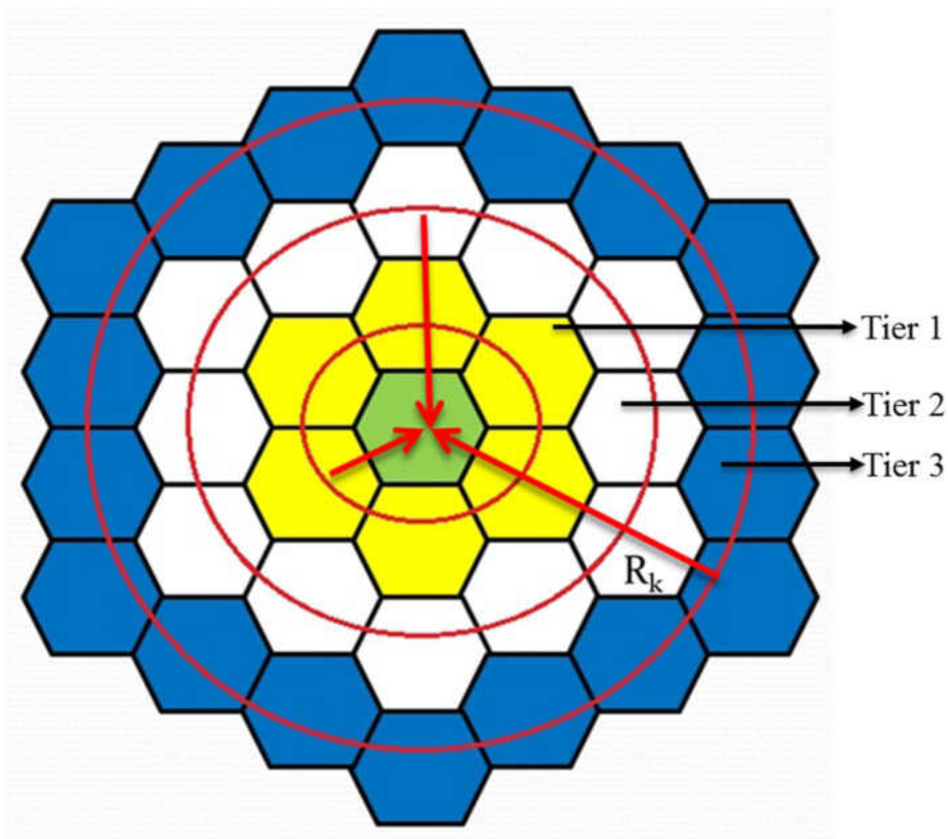

Figure 10. Out-of-cell interference coordinated by neighbor cells

As shown in Figure 10, each tier contains more cell than the previous ones and is located farther away, i.e. the number of interferers increase. For instance, the first tier contains six cells (yellow colored cells in Figure 10); the second tier contains 12 cells (white colored); the third tier contains 18 cells (blue colored), and so on. The number of cells in the k^{th} tier is proportional to the circumference of the k^{th} tier ($2\pi R_k$), where R_k is the average distance from the center cell (green colored). Hence, the total out-of-cell interference can be expressed mathematically as equation (3.11)

$$I_{total} = \sum_{k=1} I_k = \sum_{k=1} \frac{O(2\pi R_k)}{O(R_k^{\gamma})} \tag{3.11}$$

Where I_k is the total out-of-cell interference contributed by k^{th} tier neighbor cells and γ is the propagation path-loss slope exponent or single attenuation slope.

For example, for the path loss slope γ=4, $I_k = O\left(\frac{1}{R_k^3}\right)$. This means, if the path-loss slope is steep, the interference contributed from the neighbor cells that are located far away attenuate faster and the effect will be negligible.

However, if the path loss slope γ=2, then $I_k = O\left(\frac{1}{R_k}\right)$. This means, if the path loss slope is too shallow, the interference contributed from the neighbor cells will be significant. So the interference will goes up as the number of tier increases.

In the proposed Small Cell architecture, signal will attenuate faster after the cell boundary. So, the total out of cell interference will not increase if the number of tier increases.

3.3.3 Propagation Prediction Model for Proposed Architecture

According to Figure 7, a straight line equation can be formed with RSL_0 as the intercept at d_0 is below

$$RSL = RSL_0 - 10\gamma Log(\frac{d}{d_0}) \tag{3.12}$$

Where, RSL is received signal level, RSL_0 is is received signal level at Fresnel zone break point d_0, and d is the distance.

Equation (3. 12) can be rewrite as below

$$d = d_0 10^{(\frac{RSL_0 - RSL}{10\gamma})} \tag{3.13}$$

Since the cell is invariant to the propagation environment within first Fresnel zone breakpoint and signal attenuates with attenuation slope $\gamma=2$, the path loss PL_0 and received signal level can be found by free space path loss formula as below

$$PL_0 = 32.44 + 20 \log(f) + 20 \log(d_0) \tag{3.14}$$

$$RSL_0 (d = d_0) = ERP - PL_0 \tag{3.15}$$

Where, f is operating frequency band in MHz and ERP is Effective Radiated Power in Watts. By combining equation (3.14) and (3.15), one we found

$$RSL_0 = ERP - \{32.44 + 20 \log(f) + 20 \log(d_0)\} \tag{3.16}$$

Furthermore substituting equation (3.16) into (3.13), we obtain the general propagation prediction formula is obtained

$$d = d_0 10^{[\frac{ERP - \{32.44 + 20\log(f) + 20\log(d_0)\} - RSL}{10\gamma}]} \tag{3.17}$$

This forms the basis development of the proposed Small Cell deployment.

CHAPTER 4

CELL SELECTION AND HANDOVER IN SMALL CELL NETWORKS

4.1 Introduction

The deployment of traditional cellular network (including LTE) based on the assumption of a planned layout where a set of base-stations (Macro Cells) are deployed with similar characteristics such as similar transmit power, antenna patterns, receiver noise floors etc. But in case of Heterogeneous Networks, different low power nodes with different characteristics are deployed that introduces randomness of cell deployment, which also increases the challenges for selecting an optimum serving cell.

In case of a conventional homogeneous network, initial cell selection, cell reselection in idle mode, and handovers are based on the highest reference signal received power (RSRP) measured at User Equipment (UE). Although this gives the optimum selection methodology for single-layer networks, but it does not always apply to the Heterogeneous Networks (HetNets) where base stations can have different transmit powers and various coverage areas such as Macro Cells, Micro Cells, Pico Cells, Femtocells, and relays [26]. Usually, Macro Cell and Pico Cell base stations, namely MeNBs and Pico-eNBs, differ by almost 16 dB in their downlink transmit power levels.

Small Cells are deployed within the Macro Cell to increase the network capacity and avoid coverage holes by adapting varying nature of user traffic demand [27]. Since Macro Cell uses higher transmitted power compared to Small Cells, UEs are more likely to connect to Macro Cell even when the path loss condition between the UE and Small Cells are better, if the cell selection is based on RSRP only. That leads the improper cell selection and increases the probability of call drop [28]. To minimize these effects, cell-specific handoff (HO) parameter optimization is needed to consider for Heterogeneous Networks, unlike the same set of HO parameters (e.g., hysteresis margin, time-to-trigger, UE velocity, etc.) for the single layer Macro network [29]. Many cell selection schemes are proposed in [28, 30, 31, 32, 33, and 34].

4.2 Conventional Cell Selection Methods

When a UE first powers on in order to establish network attach process, it must determine the best cell to camp on (i.e., cell selection. After connecting to the network, Heterogeneous Networks have the mobility support that allows UE to move one cell to another cell in idle mode (i.e., cell reselection) and also in active mode (i.e., handover). In heterogeneous networks, two types of cell selection methods are specified. One is the Reference Signal Received Power (RSRP)-based cell selection and the other one is Reference Signal Received Quality (RSRQ)-based cell selection.

4.2.1 RSRP-Based Cell Selection

A cell is considered to be suitable cell if Reference Signal Received Power (RSRP) is greater than the minimum RSRP value specified in that cell, which ranges from -144dBm to -44dBm [22].

$$\text{CellID}_{\text{Serving}} = \arg\max_{\{i\}} \{\text{RSRP}_i\} \tag{4.1}$$

Macro Cell has larger downlink coverage due to high transmission power, but Small Cell has small downlink coverage due to low transmission power. On the other hand, the uplink coverage doesn't change, since the transmitter is a set of the UEs. Therefore, the optimum cell size for downlink and uplink are different and this introduces downlink/uplink imbalance problem. According to Release8 specifications, biasing the cell selection (i.e., Cell Range Expansion) is allowed, and the UE can then determine the best cell by the following relationship:

$$\text{CellID}_{\text{Serving}} = \arg\max_{\{i\}} \{\text{RSRP}_i + \text{bias}_i\} \tag{4.2}$$

The cell selection bias can range from 0 to 20 dB based on different propagation environment. Since the RSRP-based cell selection only reflects the received power from each cell and does not reflect the quality of the channel, the offloaded UE may suffer severe interference caused by the Macro Cell if the bias is large.

4.2.2 RSRQ-Based Cell Selection

UE can also determine the best cell based on the RSRQ value (i.e., -3dB to 19.5dB according to specification) if eNodeB is configured to do so. The RSRQ under the full load conditions is defined by: [35]

$$RSRQ = \frac{RSRP}{RSSI} = \frac{SINR}{1 + SINR} \tag{4.3}$$

Where, RSSI is received signal strength indicator, and SINR is signal-to-interference-plus-noise ratio. Since RSRQ increases with increasing the SINR, therefore it functions similarly as the SINR-based cell selection [30]. But RSRQ-based cell selection allows more users offloaded to Small Cell with high SINR compared to SINR-based cell selection. By introducing the bias, the UE selects the best cell according to the following relationship:

$$\text{CellID}_{\text{Serving}} = \arg\max_{\{i\}} \{\text{RSRQ}_i + \text{bias}_i\} \tag{4.4}$$

4.3 Proposed Cell Selection and Hand-Off Mechanism

In the proposed cell selection method, the UE determine the best cell by the value of the signal attenuation slope instead of RSRP/RSRQ. Referring to Figure 11, if any user crosses the cell boundary and moves from Cell-A (Serving Cell) to Cell-B (Candidate Cell), the user will experience a rapid attenuation of received signal strength due to a large attenuation slope. As a result prompt hand-off will take place to Cell-B, since the downlink signal from Cell-B experienced lower attenuation slope (γ=2).

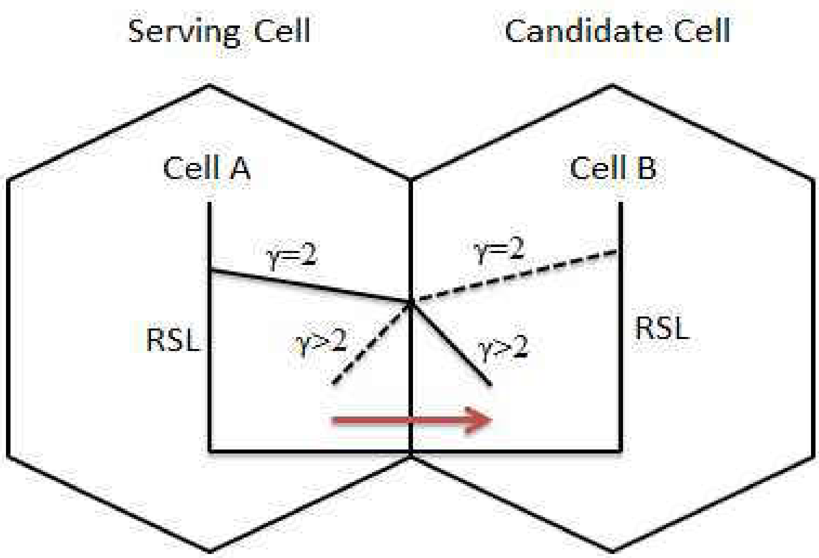

Figure 11. Proposed hand-off scenario

When the eNodeB analyses the UE measurement report, it can get information about received signal strength based on location (equation 4.5). By Tracking Area Indicator (TAI), the eNodeB can identify the UE location and can get the value of attenuation slope or path loss slope (γ) provided by the propagation model specified in that eNodeB.

$$RSL(x, y, z) \infty d^{-\gamma} (x, y, z) \quad (4.5)$$

Where, RSL(x, y, z) represents the received signal level as a function location, d(x, y, z) is the distance with respect to location, and γ is the attenuation factor provided by the propagation prediction model.

4.4 Performance Analysis of Proposed Hand-Off Mechanism

Small Cells are deployed within the Macro Cell coverage to increase the network capacity, but if we consider dense deployment of Small Cell, traffic offloading to Small Cell becomes a critical issue, as explained in the following two scenarios:

4.4.1 Scenario-1: When Small Cell Very Close to Macro Cell

Referring to Figure 12, the user is served by Small Cell but it will get stronger signal from Macro Cell, since Macro Cell has high transmission power. If the cell selection is based on RSRP/RSRQ, the user is likely to connect with Macro Cell, but in the proposed plan the user can be served by Small Cell due to lower attenuation slope ($\gamma=2$).

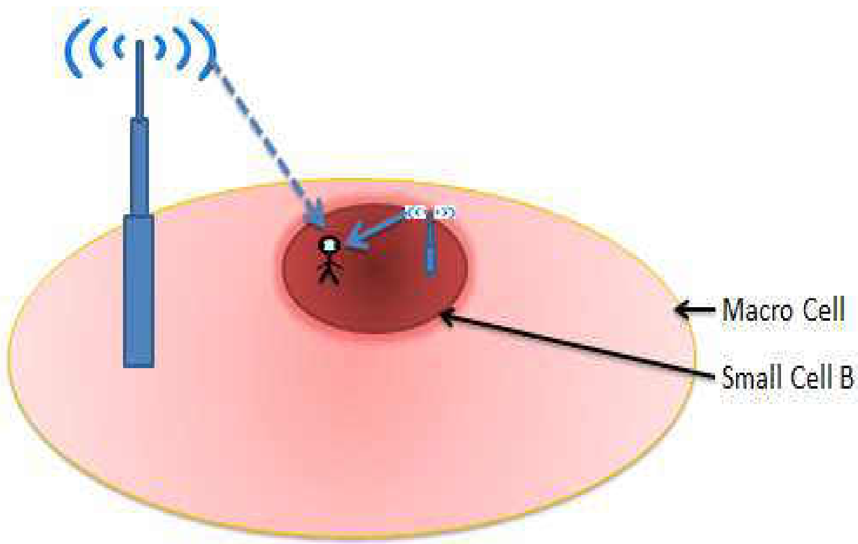

Figure 12. Proposed hand-off scenario-1

4.4.2 Scenario-2: When Two Small Cells Are Very Close

In Figure 13, the user is served by Small Cell-A but it will also get a strong signal from neighbor Small Cell-B. If the cell selection is based on RSRP/RSRQ, the user will experience lack of dominant cell and the number of handover signaling increases to find the dominant cell. This problem is solved by the proposed plan, since the out-cell interference attenuates fast due to large attenuation slope and the user connected with serving cell without interruption.

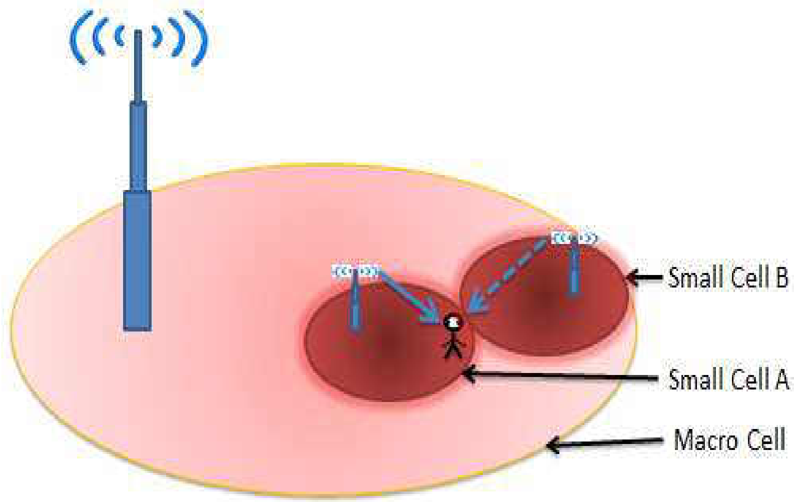

Figure 13. Proposed hand-off scenario-2

In this chapter, conventional cell selection methods for Heterogeneous Networks are studied and proposed a new cell selection method based on signal attenuation slope. It is found that the proposed cell selection method allows seamless offloading the traffic between Macro Cell and Small Cell. Thus, dense Small Cell deployment is possible to hence the network capacity without degrading the network quality.

CHAPTER 5

COVERAGE AND CAPACITY DIMENSIONING

5.1 Coverage Planning

The coverage estimation is used to determine the coverage area of each base station. Coverage estimation calculates the area where base station can be heard by the users (receivers). It gives the maximum area that can be covered by a base station. But it is not necessary that an acceptable connection (e.g. a voice call) between the base station and receiver can be established in coverage area [36]. However, base station can be detected by the receiver in coverage area.

Coverage planning includes Radio Link Budget (RLB) and Coverage analysis [37]. For the planning of any Radio Access Networks (RAN) begins with a RLB. RLB comprises the accounting of all gains and losses from the transmitter end (base station site), through the medium (i.e. free space, cable, waveguide, fiber, etc.) to the receiver end (mobile station) in a telecommunication system [38]. The maximum allowed receive signal level at the mobile station to the base station is estimated which allows to calculate the maximum path loss allows to get maximum cell range that leads to estimate a suitable propagation model. According to the cell range, it allows to estimate the total number of base station sites required to cover a required geographical area.

5.1.1 Radio Link Budget

Since operators are rightfully focused on the service quality of a system, radio network coverage becomes an important part of the service quality of a system. The main purpose of radio network planning is to keep a balanced coverage, capacity, system quality, and total cost so none of these can be considered in isolation.

The purpose of Radio Link Budge (RLB) can be sort out as follows [36]:

1. Calculate such a factor that can solely describe building penetration loss, feeder loss, transmitting antenna gain, receiver antenna gain, and the interferences.
2. Calculate the margin of the radio link to find out all the related gains and losses that can affect the whole cell coverage.
3. Based on eNodeB transmit power allocation and the maximum transmit power of the terminal, estimate the maximum link loss of a radio link.
4. Whenever estimate the maximum link loss of a radio link allowed under certain propagation model, coverage radius of a base station can be obtained. Then this radius can be used for subsequent designs.

During radio network planning designer needs to consider various factor that will affect the coverage radius of a cell and the total number of base stations required to cover any particular area. The key affecting parameters are groups as followings:

1. Propagation related parameters, such as the penetration loss, feeder loss, body loss, and background noise.
2. Equipment related parameters, such as transmit power, receiver sensitivity, and antenna gain.

3. LTE specific parameters, such as Multiple Input Multiple Output (MIMO) gain, power boosting gain, edge coverage rate, repeat coding gain, interference margin, and fast fading margin.
4. System reliability parameters, such as slow fading margin.
5. Specific features that will affect the final path gain.

Note is that the link budget is based on only theories, and it cannot ensure the system capacity and coverage reliability of the actual network. The actual coverage target and requirements also vary with different network requirements [39, 40]. Consequences, the link budget result varies greatly in reality, and depending on the different input parameters that is varied with situation and requirements. Therefore designer's need to discuss with the operator to estimate the value of each input parameter in the link budget to estimate a link budget that will reflects the requirement of a particular networks.

Link budget also assumes some parameters, such as a uniform landform, simple terrain, ideal site locations, and even subscribers distribution. The simulation covers detailed landform distribution, actual site location, terrain serves only as theoretical calculation result. This calculated coverage radius is further used as reference for simulated site distribution. For a given coverage area, the number of base stations needed depends on the simulation results.

Radio Link Budget model for uplink (UE to eNodeB) and downlink (eNodeB to UE) are shown in Figure 14 and 15.

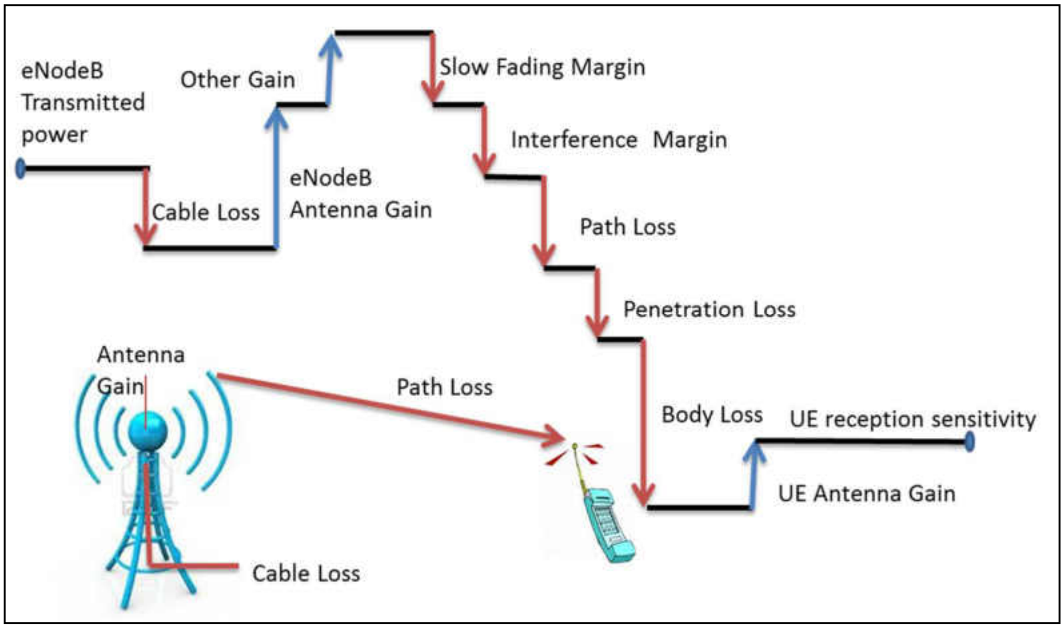

Figure 14. Downlink Radio Link Budget Model

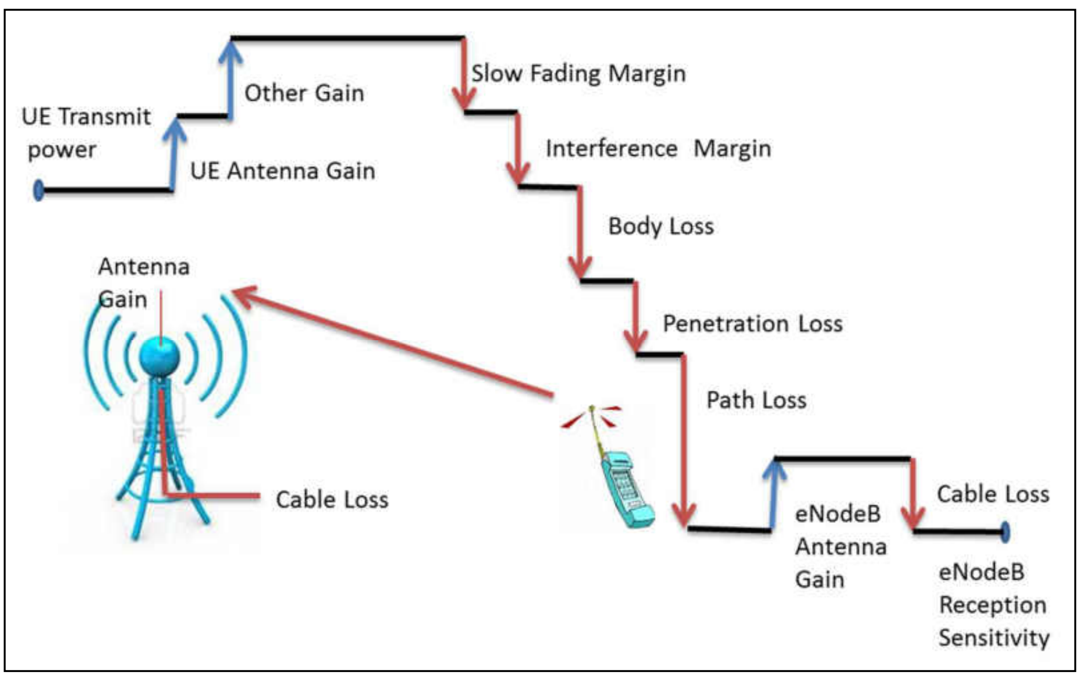

Figure 15. Uplink Radio Link Budget Model

The basic Radio Link Budget equation for LTE can be written as follows (in units of dB) [36, 25]

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - L_{TX} - L_{RX} + P_M - L_P \tag{5.1}$$

Where, the PRX is the received power (dBm). PTX is the transmitted output power (dBm). GTX and GRX is transmitter and receiver antenna gain (dBm), respectively. LTX and LRX are the cable and other losses on the transmitter and receiver side (dB) respectively. P_M is the planning margin and L_P is the path loss between transmitter and receiver end.

The maximum available transmission power is equally divided over the cell bandwidth; the average received power (AveRxPowerDL) in the bandwidth allocated to the user is derived as follows [41]:

$$AveRxPowerDL = \frac{AveTxPower}{LinkLossDL} = \frac{MaxNodeBTxPower}{CellBandwidth} \times \frac{AllocatedBandwidth}{LinkLossDL}$$

(5.2)

Where,

AveTxPower = Average transmitted power (W)

LinkLossDL = Total Link Loss in Downlink (W)

MaxNodeBTxPower = Maximum Power transmitted from eNodeB (W)

CellBandwidth = Allocated bandwidth of LTE network cell (MHz)

Allocated bandwidth= Bandwidth of channel over which the signal is transmitted

In LTE network MaxNodeBTxPower depends on the cell bandwidth and the range is from 1.25MHz to 20MHz. Specifically, MaxNodeBTxPower is 20 Watt (43 dBm) up to 5 MHz and 40 Watt (46 dBm) above this limits [42].

The average received power (AveRxPowerUL) can be written with assuming no power control as follows:

$$AveRxPower\ UL = \frac{MaxUETxPow\ er}{LinkLossUL} \tag{5.3}$$

Where,

MaxUETxPower = Max transmission power of user equipment (UE in Watt)

LinkLossUL = Total link loss in uplink (W)

The max transmission power of user equipment can be either 0.125 W or 0.25 W (21 dBm or 24 dBm) [42]. Total link loss in uplink includes the path loss which is distance dependent and all other related gains and losses at the transmitter and the receiver. In case of uplink, gains include antenna gains and amplification gains (e.g., Mast Head Amplifier in UL direction). And also, the losses include body loss, cable loss and Mast Head Amplifier noise figure at the eNodeB and finally some margins and other losses needed to take into account are shadow fading and indoor penetration loss. Therefore, link loss can be defined as:

$$Linkloss = \frac{RxGains \times TxGain\,s}{PathLoss \times RxLosses \times TxLosses \times OtherLosse\,s} \tag{5.4}$$

The received noise power (RxNoise) can defined as follows:

RxNoise = ThermalNoise × ReceiverNoiseFigure (5.5)

= (ThermalNoiseDensity × AllocatedBandwidth) × ReceiverNoiseFigure

Where,

ThermalNoise = Thermal Noise (W)

ReceiverNoiseFigure = Receiver Noise (W)

Thermal Noise Density = -174 dBm

Orthogonal Frequency-Division Multiple Access (OFDMA) is used in the downlink (DL) and if assuming the appropriate length of cyclic prefix, then we can assume that there is no own cell interference (Own Cell Interference is Zero). But there will be Other Cell Interference which is the total average power received from other cells in the allocated bandwidth. Similarly, in the UL direction the Interference (also called Noise Rise) is the power received from terminals transmitting on the same frequency in the neighboring cells (Other Cell Interference) [43].

Above set of equations lay the basis for calculation of RLB equation for maximum allowed path loss. Here, we get the result

$$SINR = \frac{AveRxPwr(own)}{1+N} = \frac{AveRxPwr(own)}{1(other)+N} = \frac{\frac{AveTxPwr(own)}{LinkLoss(own)}}{\sum_{k \neq own} \frac{AveTxPwr(k)}{LinkLoss(k)} + N} \quad (5.6)$$

$$= \frac{\frac{1}{LinkLoss(own)}}{\sum_{k \neq m} \frac{1}{LinkLoss(k)} + \frac{CellBW}{MaxTxPwr} \times ThermalNoiseDensity \times RxNoiseFigure} \quad (5.7)$$

LTE radio network requirements are as follows:

$$\text{SINR} \geq \text{Required SINR} \quad (5.8)$$

Now putting this in the above equation we get the following form of Path Loss:

$$PathLoss(own) \leq \frac{1}{(\sum_{k \neq own} \frac{1}{PathLoss(k)} + NoiseComponent) \times RequiredSINR}$$

(5.9)

a) Interference (i): To include the effect of interference, Other-to-own cell interference for DL can be written as follows

$$i = \sum_{k \neq own} \frac{PathLoss(own)}{PathLoss(k)} \tag{5.10}$$

Rewriting this equation according to RequiredSINR requirements as follows

$$\frac{1}{i + NoiseComponent \times PathLoss(own)} \leq RequiredSINR \tag{5.11}$$

Thus, the maximum path loss LTE can write as follows:

$$MaxPathLoss = \frac{1 - i(MaxPathLoss) \times RequiredSINR}{NoiseComponent \times RequiredSINR} \tag{5.12}$$

Therefore it is found that all the conventional RLB components are in the Noise Component. Noise component is the inverse of the conventional path loss [43, 44].

In case of uplink the issues of interference is dealt as interference margin which can be calculated using the following equation:

$$\text{Interference Margin} = \frac{SNR}{SINR} \tag{5.13}$$

Where,

SNR = Signal to noise ration

SINR = signal-to-interference-plus-noise ratio

b) Spectral efficiency: Whenever cell edge of a particular cell is defined according to required throughput, the corresponding spectral efficiency has to be derived. According to Alpha-Shannon formula Spectral efficiency of a radio network can be written as follows [11]:

$$SpectralEfficiency = \alpha \times \log_2(1 + 10^{\frac{SNR}{10}}) \tag{5.14}$$

The maximum capacity of the LTE radio network cannot be obtained due to the following factors:

1. Limited coding block length
2. Frequency selective fading across the transmission bandwidth
3. Non-avoidable system overhead
4. Implementation margins (channel estimation, CQI)

From above equation there are two factors that affect the Shannon formula to LTE radio link is the following:

1. Bandwidth efficiency factor (α)
2. SNR efficiency factor, denominated Impact Factor

So, the modified Alpha- Shannon Formula can be written as:

$$SpectralEfficiency = \alpha \times \log_2(1 + 10^{\frac{SNR}{10 \times ImpactFactor}}) \qquad (5.15)$$

c) Required SINR: For a given cell throughput cell edge of a particular cell is solely depends on the Required SINR value. That's why required SINR becomes the main performance indicator for LTE Radio network. Required SINR is depends on the following two factors [45]:

1. Modulation and Coding Schemes (MCS)
2. Propagation Channel Model

As higher the modulation and coding schemes used, higher the required SINR is required. For example using Quadrature Phase Shift Keying (QPSK) has a lower required SINR compared to 16QAM (quadrature amplitude modulation).

Maximum allowed path loss of a LTE Radio Network is calculated according to the following condition:

$$\text{SINR} \geq \text{Required SINR} \tag{5.16}$$

$$\text{SINR} = (\text{AveRxPower})/(\text{Interference}+\text{RxNoise}) \tag{5.17}$$

Where, SINR is Signal to Interference and Noise Ratio. AveRxPower is average received power (W). Interference is interference power (W) which comprises the own channel interference (i.e., Power due to own cell interference) and Other Cell Interference (i.e., power received for neighboring cells). RxNoise is the receiver noise power which includes thermal noise and receiver noise figure.

5.1.2 Coverage Analysis

Coverage analysis gives the estimation of the resources needed to provide service in the deployment area with specific system requirements. Since the LTE system allow providing high quality of service and high capacity, estimating inaccurate coverage has severe impact on the system performance. Over estimating the coverage area causes received signal level at a distance from base station weaker than the minimum required threshold [46, 47]. And even under estimating the coverage area results in coverage area overlap, which causes interferences and degrade the system performance. Thus, accurate estimation of coverage is the key to design a good radio network. In this section, the cell radius of a particular LTE sector is calculated based on the propagation environment.

When the received signal is measured over the distance of a few tens of wavelength, the receive signal level shows rapid and deep fluctuations about the local mean with the movement of user equipment (e.g., mobile terminal). It is difficult to describe by mathematical equations because the Radio Frequency (RF) propagate through transmitter end to receiver end depends on lots of factor such as, proximity to buildings, the actual terrain, antenna heights, topology, morphology, Etc. That's why the selection of a suitable RF propagation model for LTE radio network is of great importance [48, 49].

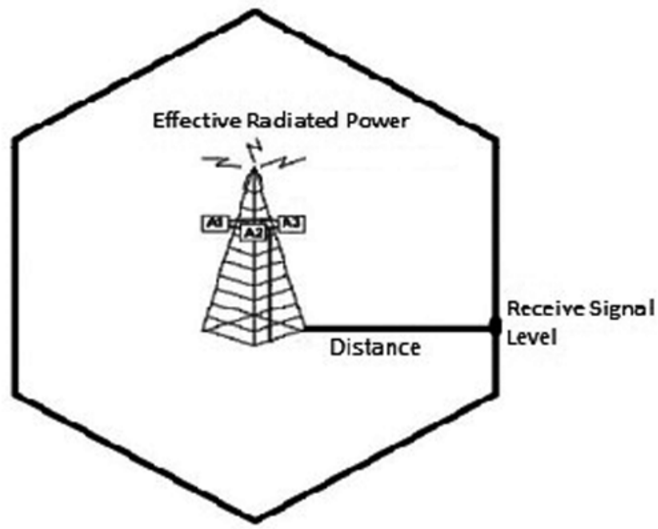

Figure 16. Receive Signal Level at a distance d from the base station

RF propagation model describes the behavior of the transmitted signal while it is transmitted from transmitter end towards the receiver end, as described in section 5.1.3. It gives the relation between transmitter and receiver end and from this relation designers can get an idea about the maximum allowed path loss between transmitter and receiver end and can estimate the maximum cell range, shown in Figure 16.

As shown in Figure 14 and 15, designers can easily estimate the transmitted output power, transmitter and receiver antenna gains, the cable and other losses on the transmitter and receiver sides but the designers cannot predict path loss between the medium of transmitter and receiver end. The path loss criteria are solely depends on the RF propagation environment (urban, rural, dense urban, suburban, open, forest, sea etc.), operating frequency, atmospheric conditions, indoor/outdoor & the distance between transmitter end & receiver end.

Note that empirical formulas do not estimate the actual coverage needed for designing a network. Several computer based prediction tools [48] model that uses the physical phenomenon of RF propagation using terrain and clutter (land use) data. To get the accuracy of coverage estimation using these tools depends on the accuracy and resolution of the available data. Even when accurate and high resolution clutter data is available, the effect of the clutter on the RF propagation may different due the different of areas. For example, if the clutter data classifies an area as dense urban considering, average building height, there is still an ambiguity found about the density of the buildings in the area and also RF propagation depends on the materials used to construct the buildings [50]. Also the propagation characteristics in an area classified as dense urban in one country will never be equal in another country. That's why designers always need lots of simulation before deploying any network and it saves lots of money of an operator.

5.1.3 Okumura-Hata Propagation Prediction Model

The most widely used radio frequency propagation model for predicting the behavior of cellular propagation is the Hata Model for Urban Areas, also known as the Okumura-Hata model for being a developed version of the Okumura Model. This model incorporates the effects of diffraction, reflection and scattering caused by different city structures.

Okumura model for urban was the first model and used as the base for the others. According to Okumura-Hata propagation model there are four different types of propagation environment and considering each propagation environment there is a propagation model [25].

1. Dense Urban Model
2. Urban Model
3. Sub-Urban Model
4. Rural Model

The traditional Okumura-Hata model for path loss formula is given by [25]

$$Lp(dB)=C_0+C_1+C_2 \log(FMHZ)-13.82 \log(Hb)-a(Hm)$$
$$+[44.9-6.55 \log(Hb)] \log(dKm) \quad (5.18)$$

Where C_0, C_1 and C_2 are constants and are given

C_0 = 0 for Urban

= 3 dB for Dense Urban

C_1= 69.55 for 150 MHz to 1000 MHZ

= 46.30 for 1500 MHz to 2000 MHz

C_2 = 26.16 for 160 MHz to 1000 MHz

= 33.90 for 1600 MHz to 2000 MHz

f = Frequency in MHz

d = Distance (cell radius) in Km

Hb = Base station antenna height in meters

for Urban,

$$a(Hm) =\{1.1 \log (FMHz) - 0.7\}Hm - \{1.56 \log (FMHz) - 0.8\} \quad (5.19)$$

for Dense Urban,

$$a(Hm) = 3.2[\log\{11.75\ Hm\}]2 - 4.97 \quad (5.20)$$

Hm = Mobile Antenna height in meters

From equation (5.18) we can find the cell radius

$$dKm = \text{anti log}\ [\{Lp(dB)-C0-C1-C2\ \log(FMHZ)+13.82\ \log(Hb) + a(Hm)\}/\ \{44.9-6.55\ \log(Hb)\}] \quad (5.21)$$

Using this cell radius the cell coverage area of a particular cell can be calculated and it is depended on the site configuration. Designers consider hexagonal cell for design purpose although the deployment area is irregular in shape. For hexagonal cell models, cell coverage for omni-directional sites, Bi-sector sites, and tri-sector sites can be calculated by equations 5.22, 5.23, and 5.24, respectively.

Site coverage area (Omni-directional site) = 2.6 * CellRadius2 (5.22)

Site Coverage area (Bi-sector site) = 1.3 * 2.6 * CellRadius2 (5.23)

Site Coverage area (Tri-Sector site)= 1.95 * 2.6 * CellRadius2 (5.24)

5.2 Capacity Planning

Capacity planning is crucial to estimate the resources needed for supporting a specified offered traffic with a certain level of QoS (e.g. throughput or blocking probability) [45]. Theoretical capacity of the network is limited by the number of cells installed in the network. In short the capacity dimensioning can be described by the flowchart, shown in Figure 17. Total number of sites need to cover a geographic area can be found after calculating the number of sites based on coverage and number of sites based on capacity.

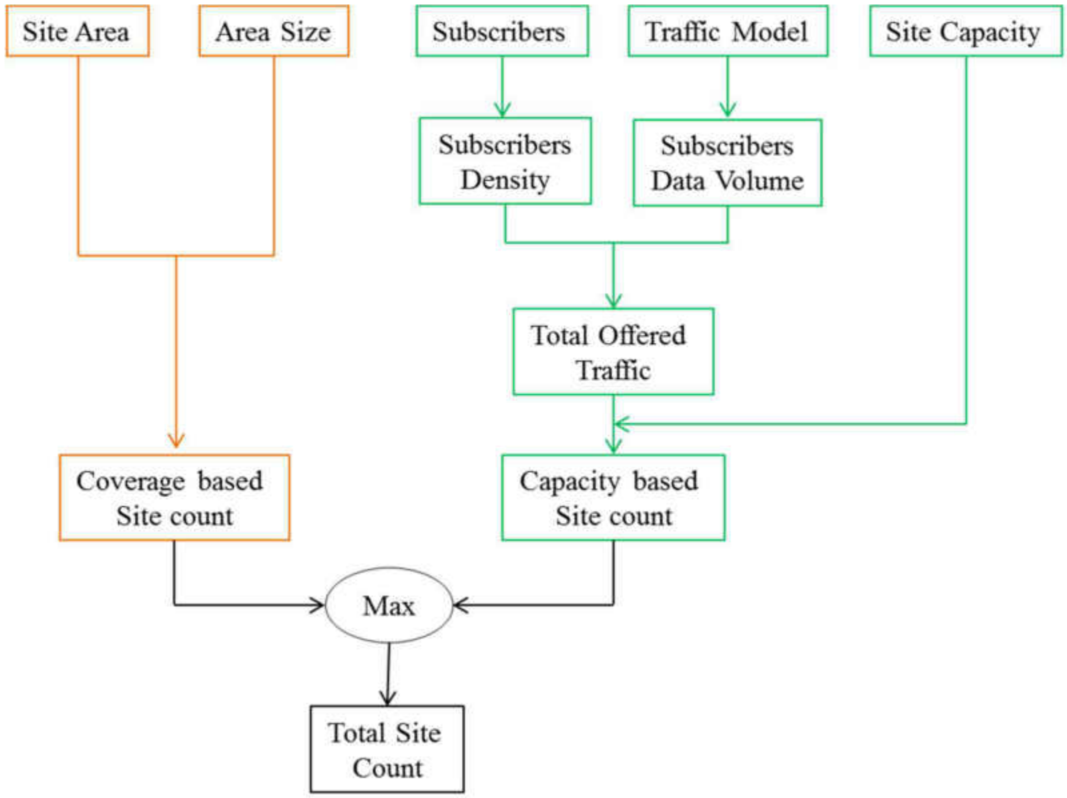

Figure 17. Capacity Dimensioning

5.2.1 Number of Sites due to Coverage

Total number of sites needed to cover a deployment area can be calculated as follows:

$$\text{Total Number of Sites} = \frac{DeploymentArea}{SiteCoverageArea} \tag{5.25}$$

Where, Deployment Area is the planned area needed to cover by network and Site Coverage Area can be calculated from the radio link budget, the propagation model and the type of cell site (discussed in section 5.1.3).

5.2.2 Number of Sites due to Capacity

The first step is to find the subscriber density. Subscriber density for a particular operator depends on the population density of the planned area, mobile phone penetration, and operator market share.

The second step is to find the subscriber's data usage requirement. The main purpose of the traffic model is to describe the behavior of the average subscriber during the most loaded day period (e.g., the Busy Hour time). Different data types are given below

a). **Voice:** Calculate the Erlang per subscriber for voice call during busy hour of the network

b). **Video Call:** Calculate the Erlang per subscriber for video call during busy hour of the network

c). **NRT Data:** Calculate the average throughput (kbps) needed per subscriber during busy hour of the network and find the target bit rates.

The third step is to calculate the total offered traffic. Total offered traffic can be calculated after finding the total number of subscriber and the average data rates per subscriber during busy hour time. Let's consider an example. In this example, the total number of subscriber is known as P and the average data volume per subscriber per busy hour (BH) found is N MByte. Now, the average data rate per subscriber can be calculated as

Average date rate per subscriber = Average Data Volume per subscriber per BH (bit)/3600s (5.26)

The total offered traffic can be calculated as

Total offered traffic=Number of Subscriber * Average Data Rate per subscriber (5.27)

The next step is to find out the site capacity and it can be calculated as

Site capacity = Cell Capacity * Number of Cells per site (5.28)

Where, cell capacity is defined as the overall cell throughput [51].

The last step is to find the capacity base site count and it can be calculated as

Sites due to capacity = Roundup (Total Offered Traffic/Site Capacity) (5.29)

5.3 Factors Affecting the Cell Capacity

Based on the fundamental limit given by the Shannon's capacity formula, the maximum number of bit/sec/m^2 is given by the following equation

$$C = \lambda n w Log_2 (\frac{P(\lambda)}{I(\lambda) + N}) \quad (5.30)$$

Where,

λ = Base station density

n = No. of signaling dimensions: MIMO "multiplexing" gain

W = Bandwidth

I(λ) = Interference Power

P(λ) = Received signal power, and

N = Noise signal power

The cell capacity can be optimized based by optimizing the different factors in equation 5.30. There are several factors that can impact on network capacity. The major factors are discussed below

5.3.1 Cell Range (Pathloss)

Path loss condition is greatly varies with different geographic area and it has great impact on inter site distance. Besides, the inter site distance (ISD) impact on network capacity because as the ISD goes up the number of site can deploy in an area is going down, so the total network capacity will goes down as well. So, the base station density can be optimized by minimizing the ISD. In real planning scenarios, ISD obtained from radio link budget is not equal to the ISD obtained in the radio network simulation (e.g., ATOLL). Therefore additional interpolation is required to adapt the results from the radio link budget.

5.3.2 Channel Bandwidth

Due to the maximum frequency diversity gain, the best capacity performance can be achieved with the wider channel bandwidth. The available maximum bandwidth in case of LTE is 20MHz. So next generation cellular networks (e.g., 5G) looking for wider bandwidth called millimeter wave wireless communications (i.e., 3- 300 GHz). According to equation 5.30, linear capacity gain is possible by adding more bandwidth but it requires expensive resources.

5.3.3 Cell Load

Full resource utilization means the 100% cell load. It will be the worst case in terms of interference, shown in the following Figure 18. The center black color cell is fully loaded all the time is the victim cell for which the overall cell throughput is measured. The surrounding cells are not fully loaded and impact the victim cell by inter-cell interference which depends on the neighbor cell load condition. When the neighbor cell load decrease the victim cell throughput is increased. So, the cell load condition can have great impact on cell capacity.

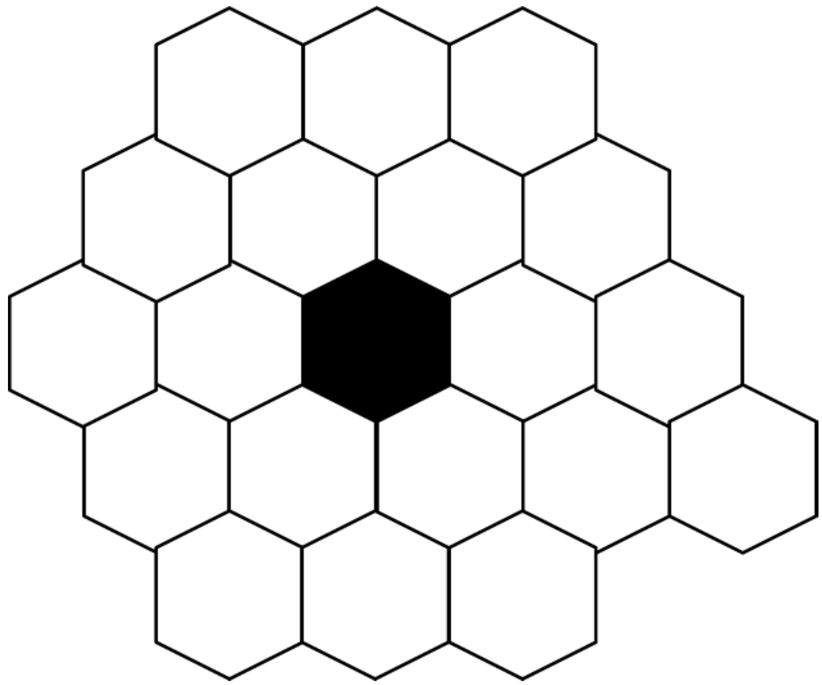

Figure 18. Impact of cell load

In this chapter describes the coverage and capacity dimensioning of Heterogeneous Networks. The different factors that affect the coverage and capacity planning is also outlined. In the next chapter shows different interference scenarios of Heterogeneous Networks and the interference coordination techniques.

CHAPTER 6

INTERFERENCE IN SMALL CELL NETWORKS

6.1 Interference Challenge

In general, interference occurs when two or more devices are transmitting close each other (i.e., the devices are physically near each other and transmitting with same or nearby frequencies or channels). Since Heterogeneous Networks is not handled by carefully network and frequency planning, the interference issue is more challenging in Heterogeneous Networks than homogeneous networks. Intra-tier interference occurs in heterogeneous networks like as homogeneous networks, where a Macro Cell interfere with neighbor Macro Cells and a Small Cell (e.g., Femtocell) interferes with neighbor Small Cells. However, the most severe interference occurs in the cross-tire interference; where Macro Cell interfere with Small Cells or a Small Cell interfere with Macro Cells [52].

In heterogeneous networks different type of cells can co-exist and the cells differ in their own characteristics. So the uses of different backhaul links introduces more challenges in interference coordination schemes, where each link supports different bandwidth and delay constraints (e.g., Pico Cells and relays use X2 interface whereas Femtocells use xDSL for exchanging signals) [53]. The main reasons that cause interferences in heterogeneous networks are discussed below:

6.1.1 Power Difference

In heterogeneous networks, Macro Cells and Small Cells are differ strongly in downlink transmit power that leads to a particular interference challenge (i.e., downlink uplink imbalance problem), shown in (Fig. 19). Since the Macro Cells transmit in high transmission power (e.g., 43dBm), the downlink coverage of Macro Cells are much higher than of Small Cells. On the other hand, the uplink coverage does not affect by the difference in downlink transmit power, since the transmitters (i.e., UE or mobile users) are same for the Macro Cells and Small Cells [32]. So, the optimum cell will be different for downlink and uplink connection. As a result, when UE is connected to one cell (serving cell) and come closer to another cell (non-serving cell or neighbor cell), it will receive high power from the non-serving cell interfering it's downlink. Several interference scenarios are discussed in section 5.2.

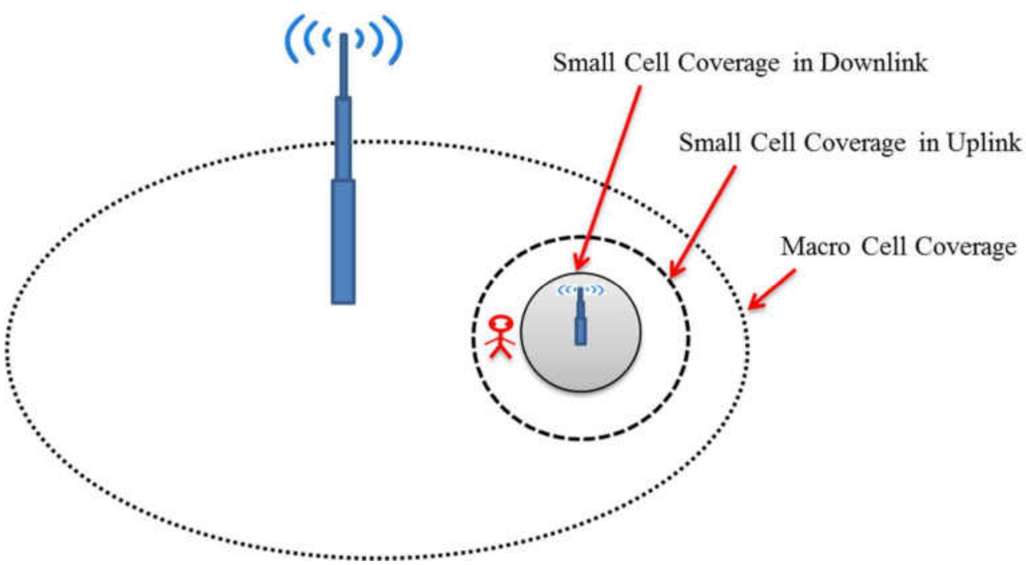

Figure 19. Problem caused by difference in power between Macro and Small Cells

6.1.2 Unplanned Deployment

In heterogeneous networks, Small Cells can be deployed and monitored by the subscriber which is not a planned deployment [54]. The networks operator doesn't have any control on them that causes load-neighbor effect. Thus, network planning and optimization becomes inefficient that leads to decentralize the interference management schemes, where the interference management schemes are applied each cell independently (e.g., Self Organizing Networks) by using the local information to achieve efficient gain for the network.

6.1.3 Closed Subscriber Group (CSG) Access

In heterogeneous networks, some Small Cells (e.g., Femtocells) can be configured as closed subscriber group access, where network access is restricted by the owners and the approved users can only get the access of the networks [55]. As a result, when any user comes near a closed subscriber group access node and cannot get access due to outside users, it will suffer cross-tier interference. In this case, the victim users starts to transmit at higher power to compensate the path loss for the it's far away serving Macro Cell that leads to jamming the unlink of the nearby closed subscriber group access node [29].

6.2 Small Cell Interference Scenarios

A set of interference scenarios for the deployment of Small Cell is discussed in this section [6, 8, 22]. In the following analysis, SC UE represents user served by the Small Cell, Macro UE represents, user served by the Macro Cell, and the red dotted line represents interfering signal.

6.2.1 Macro Cell Downlink to the Small Cell UE Interference (Traffic Channel)

The first interference mechanism to consider is where the Small Cell users interfered by the downlink signal of Macro Cell, shown in (Fig. 20). In this scenario, the Small Cell and the Macro Cell use the same spectrum for serving their related UEs. If the signal of the Macro Cell is strong at the location of the SC UE, the SC UE will be interfered by the Macro Cell that serves its UEs by the same radio resources.

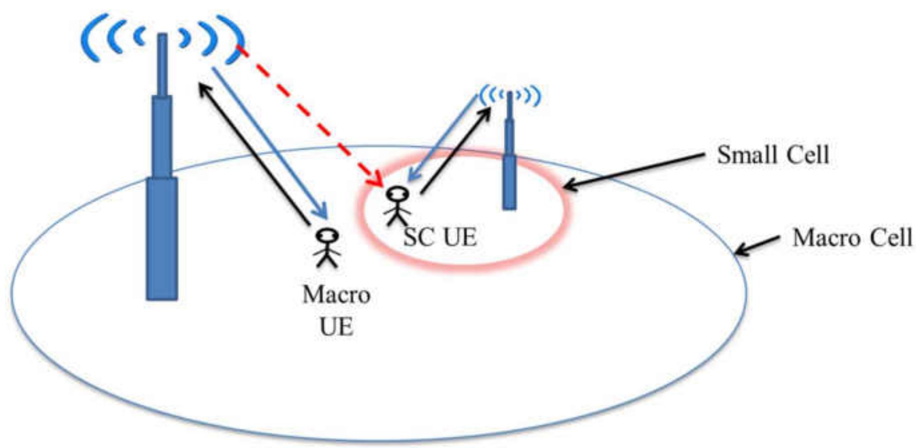

Figure 20. Macro Cell Downlink to the Small Cell UE Interference

6.2.2 Macro Cell UE Uplink to the Small Cell Interference (Traffic Channel)

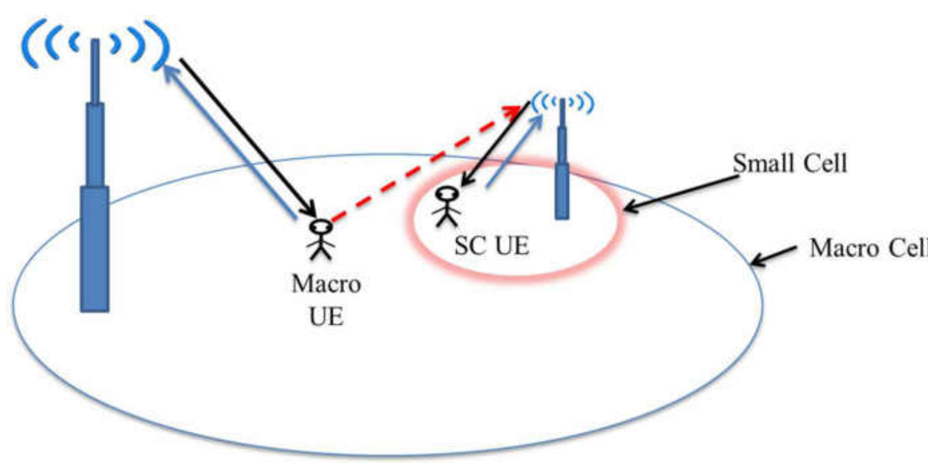

Figure 21. Macro Cell UE Uplink to the Small Cell Interference

The second interference mechanism to consider is where the Macro Cell user interfered by the uplink signal of Small Cell. In this scenario, one UE is served by the Macro Cell is close to the SC which is remote from the Macro Cell. Since the macro UE is remote from its serving Macro Cell it will transmit high power signal to reach it. However this signal might reach the SC with high enough power to interfere with the reception of the uplink signal arriving from the SC UE, shown in (Fig.21).

6.2.3 Small Cell Downlink to the Macro Cell UE Interference

According to (Fig.22) a Macro UE is served by a Macro Cell, but when it comes closer to the Small Cell, the Macro UE is interfered by the Small Cell downlink signal.

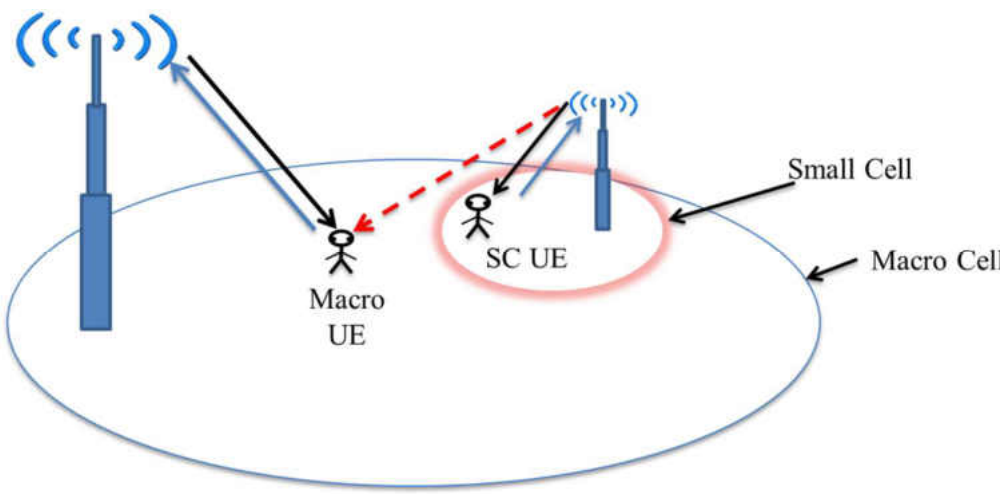

Figure 22. Small Cell Downlink to the Macro Cell UE Interference

If the downlink signal of the Small Cell provides better service than the Macro Cell, it may trigger the handoff request to the Small Cell. In this case, if the Small Cell is configured a closed subscriber group policy, this handoff request will not successful and the victim Macro UE will suffer severe disturbances without additional interference mitigation mechanism.

6.2.4 Small Cell UE Uplink to the Macro Cell Interference

Here is another interference scenario, where Macro UE is interfered by the uplink signal of SC UE, shown in (Fig.23). In the following this scenario, a faraway Macro UE is served by the Macro Cell and receives its uplink signal. Besides, a SC UE, served by the Small Cell transmits high enough power to interfere with the reception of the uplink signal arriving from Macro UE. This scenario can be more obvious in the following example (Fig.24)

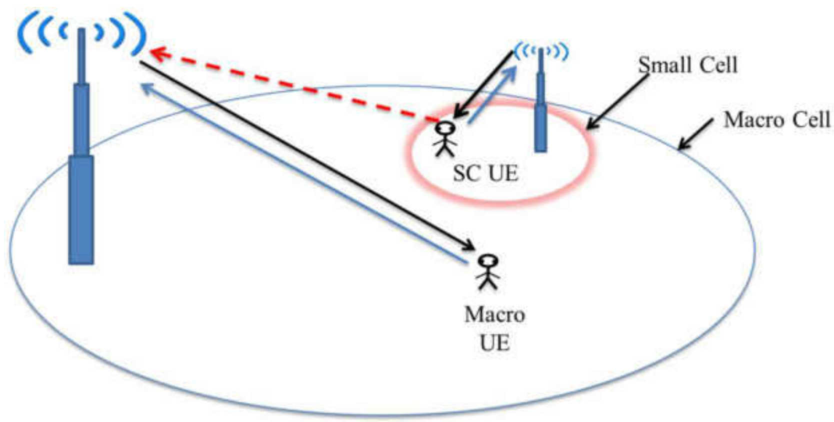

Figure 23. Small Cell UE Uplink to the Macro Cell Interference

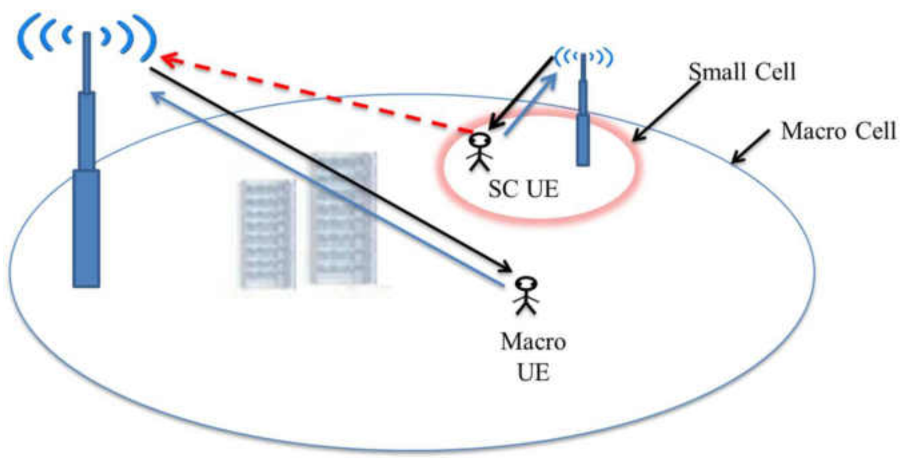

Figure 24. Small Cell UE Uplink to the Macro Cell Interference (Example)

Let's a SC UE is located on a top floor with a line of sight to the Macro Cell and a Macro UE is located far away from the Macro Cell and its communication path to the Macro Cell antenna is obscured by buildings or by other obstructions. It is assumed that both UE is transmitting at maximum power level. Since the maximum power levels of the UEs are usually identical, Macro Cell might receive significantly higher uplink signal from SC UE compared to Macro UE and therefore Macro UE will suffer severe interference without additional interference mechanism technique.

6.2.5 Small Cell Downlink to the nearby Small Cell UE Interference

This interference mechanism is considered for indoor scenario like multistoried buildings, where one Small Cell users interfered by the downlink signal of neighbor Small Cells. In the following example shown in (Fig.25), SC UE1 is served by the Small Cell1.When SC UE1 comes closer to Small Cell 2, it will still serve by the Small Cell 1 but it might receive strong interfering downlink signal from Small Cell 2. In this case, SC UE1 will trigger handoff to Small Cell 2 but if Small Cell 2 is configured closed subscriber group then this handoff request will not successful. Therefore this kind of system will perform poorly without any additional interference mechanism technique.

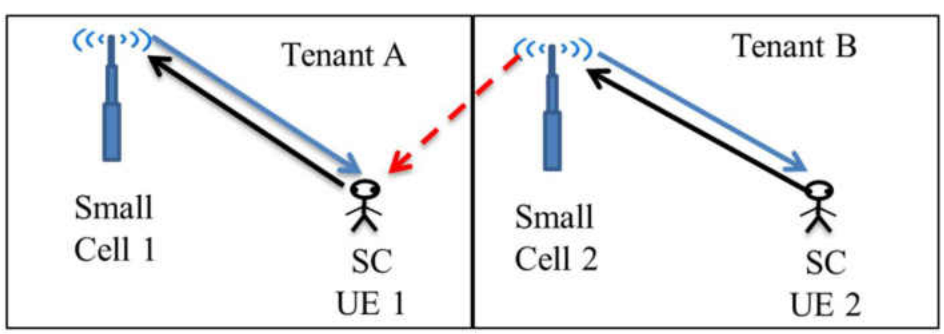

Figure 25. Small Cell downlink to the nearby Small Cell UE Interference

6.2.6 Small Cell UE Uplink to the nearby Small Cell Interference

This is the second interference mechanism considered for indoor scenario like multistoried buildings, where one Small Cell users interferes the uplink signal of another Small Cell users.

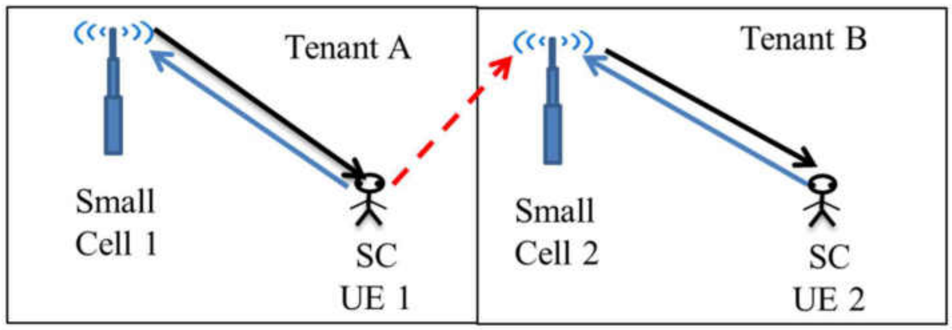

Figure 26. Small Cell UE Uplink to the nearby Small Cell Interference

According to (Fig.26), SC UE2 is served by the Small Cell 2 and SC UE1 is served by the Small Cell1. When SC UE2 move away from Small Cell 2 and the SC UE1 come closer to Small Cell 2, it might interfere the uplink signal of SC UE2. It can happen when the path loss condition between Small Cell 1 and SC UE1 becomes high, SC UE1 starts transmitting with high power. Thus a significant interference might occur. Again, without an additional interference mitigation mechanism this kind of system cannot perform well.

6.3 Interference Coordination in Heterogeneous Networks

In 3GPP LTE Release 10 introduces enhanced inter-cell interference coordination (eICIC) mechanism to deal with the interference issues in Heterogeneous Networks, and minimize interference on traffic and control channel. The techniques can be group into frequency domain techniques, time domain techniques, and power control based solution. All the techniques are discussed in this section.

6.3.1 Frequency Domain Techniques

In inter-cell interference coordination (ICIC) technique, system spectrums are allocated for interference cells by partitioning. Carrier Aggregation (CA) is introduced in 3GPP LTE Release 10 that brings additional opportunities for frequency domain interference mitigation [54]. It allows users to transmit/receive simultaneously on multiple carriers. In case of CA-based ICIC techniques, CA creates protected component carrier (CC) for each users in victim layers, where the data is received on scheduled cross-carrier components, shown in (Fig.27) [55].

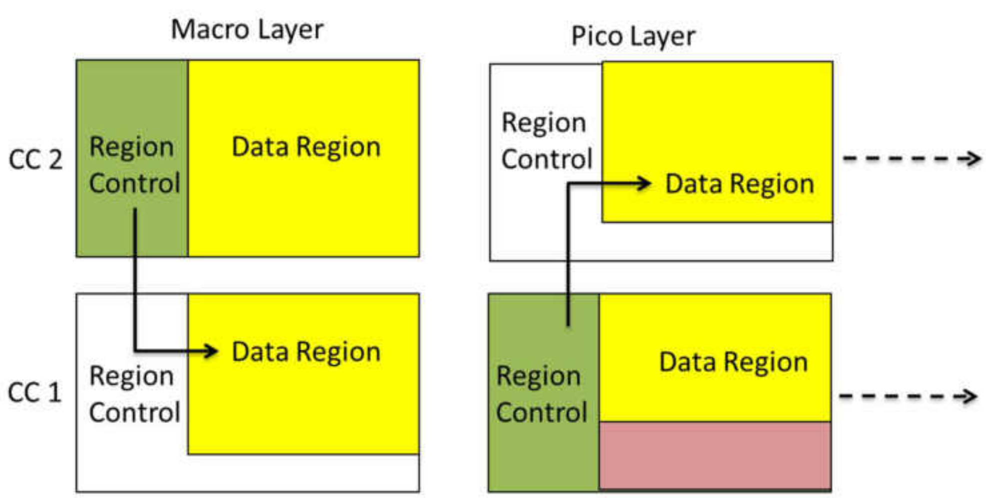

Figure 27. Frequency domain eICIC Techniques

For the deployment of Macro-Pico scenario, the macro node is the aggressive node, whereas the Pico users are the victim users. After applying the CA-based ICIC techniques, Macro Cell mute it's control channel transmission on one carrier (CC1) and it schedules users on both carriers by using the control region from the second carrier (CC 2). Thus there will be no interference in the control region for the cell edge users. In case of Pico nodes, CC1 is used for scheduling and CC2 is used to mute the control channel transmission [56].

6.3.2 Time Domain Techniques

The second eICIC technique is time domain techniques, where resources are partitioned for victim users by creating protected sub-frames. It can be done by muting or reducing the transmission power of the aggressor nodes [29]. Cell range expansion (CRE) technique is used to minimize the downlink uplink imbalance that occurs due to transmission power difference between Macro Cell and Small Cell [32]. But the users in expansion area can suffer severe interference (details in section 6.1.1). In case of Macro-Pico deployment with CRE, the aggressor nodes are Macro Cells.

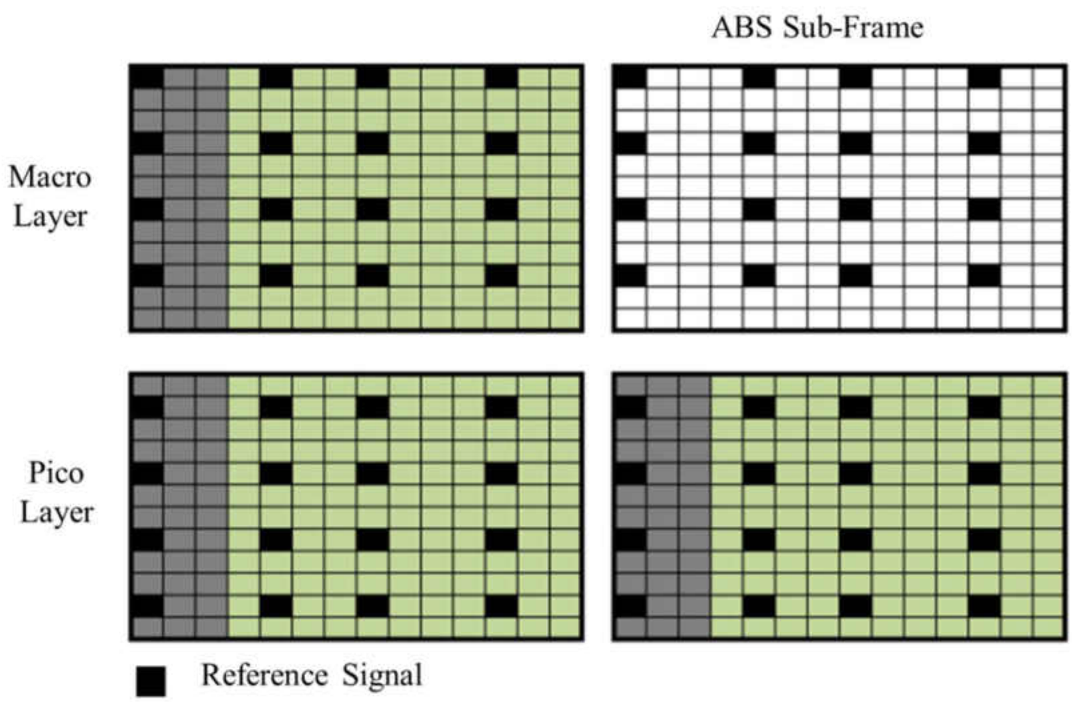

Figure 28. Time domain eICIC Techniques.

In time domain eICIC, ABS (almost blank sub frames) is used for the Macro Cell where no control or data signals is transmitted except reference signals. All the users in extension area are scheduled within the sub-frames overlapping with ABS of the Macro Cells, which mitigates the cross-tier interference significantly.

6.3.3 Power Control Based Solution

Power control based eICIC technique is used to mitigate the interference for the Macro-Femto deployments scenario. After applying this technique, Femto cell can automatically adapt its transmission power and users connected to them by observing the interference conditions, deployments, and cell loads, etc. It is noted that, power reduction is not applied in the Macro Cell because it will reduce the Macro Cell coverage [29].

In this chapter describes mobility management challenges in Small Cell networks and shows different interference scenarios. This chapter also shows possible interference coordination mechanism for Small Cell networks. The following chapter shows simulation and results.

CHAPTER 7

SIMULATION AND RESULT

7.1 Calculating Small Cell Radius

In the proposed Small Cell architecture, the radius of Small Cell is less than the first Fresnel zone break point and can be calculated by equation (3.10). According to this equation, the Fresnel zone break point varies with different antenna heights and operating frequency band. The first simulation result shows the different values of Small Cell radius (e.g., for indoor d=50m and for outdoor d=294m) by varying the transmitting antenna height, shown in (Fig. 29). In this simulation, receiver antenna height is considered as 1.5m, and operating frequency band is 2100MHz.

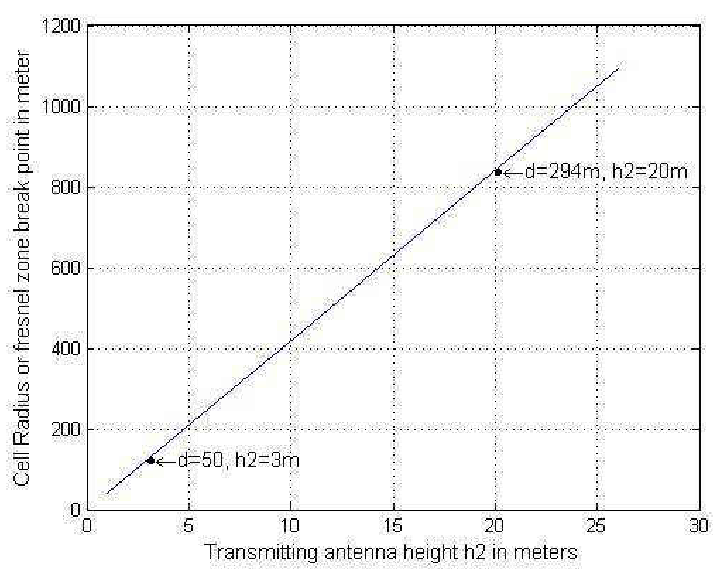

Figure 29. Fresnel zone break point varies with Tx height (F=2100MHz, h1=1.5m)

The second simulation result shows the different values of Small Cell radius (e.g., for f=2100MHz, d=840m and for f=3.5GHz, d=1400) by varying the operating frequency band, shown in (Fig. 30). In this simulation, receiver antenna height is considered as 1.5m and transmitting antenna height as 20m (for outdoor scenario).

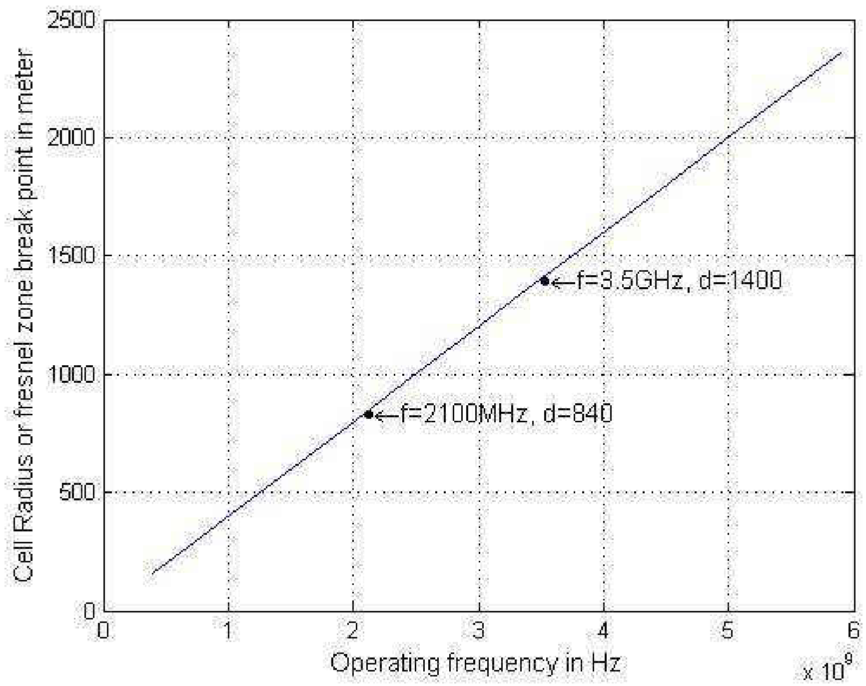

Figure 30. Fresnel zone break point varies with TX Height (h1=1.5m, h2=20M)

The third simulation result shows the different values of Small Cell radius (e.g., for f=2100MHz, d=126m and for f=3.5GHz, d=210) by varying the operating frequency band, shown in Figure 31. In this simulation, receiver antenna height is considered as 1.5m and transmitting antenna height as 3m (for indoor scenario).

Based on Figure 29, 30, and 31, it is obvious that for different deployment environments (e.g., indoor or outdoor), the service provider can optimize the Small Cell radius by adjusting the transmit antenna height with any specific operating frequency band.

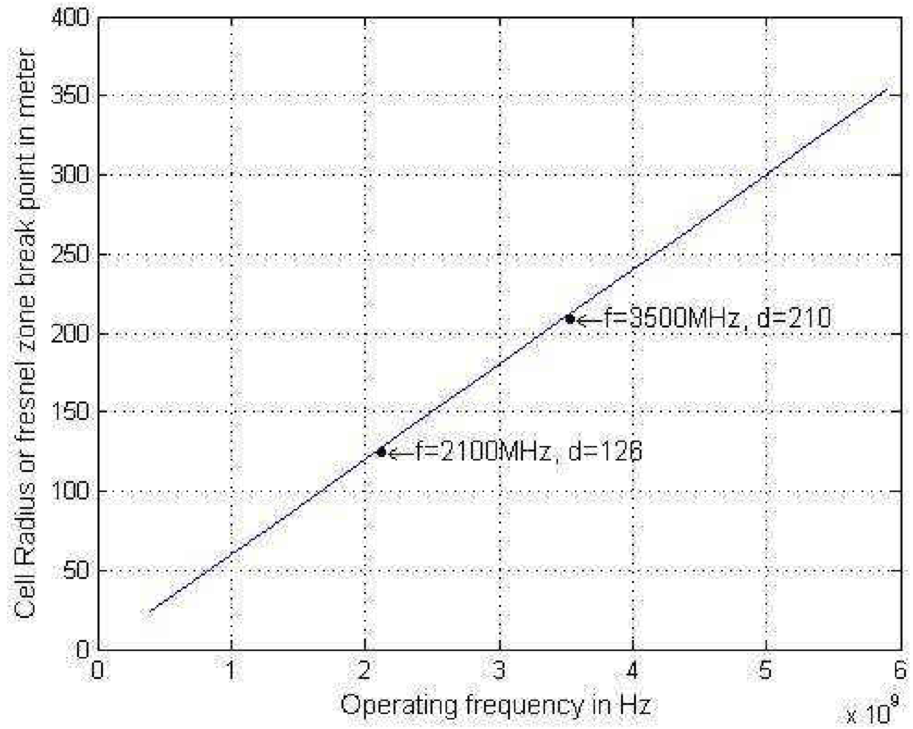

Figure 31. Fresnel zone break point varies with Tx height (h1=1.5m, h2=20M)

7.2 Multipath Effect in Proposed plan

This simulation result shows how the multipath signal can affect the received signal level over a distance. For multipath effect analysis the following simulation parameters listed in Table 2.

Table 2. Simulation parameter for multipath effect in proposed plan

Cell Type	Transmitter Height	Receiver Height	Operating Frequency	RSL (dBm)
Indoor	3m	1.5m	2100MHz	-70dBm
Outdoor	6m	1.5m	2100MHz	-70dBm

It is found that the Small Cell is insensitive to the propagation environment with ERP=10.98mW and the corresponding cell radius is 126m (indoor cell Figure 32). But doubling the transmitting antenna height (for outdoor) the cell radius becomes double 252 and the corresponding ERP=49mW (Fig.33). It is also found that the Small Cell becomes more sensitive to the environment as the transmit power increases, since the signal affected by multipath fading beyond the first Fresnel zone break point.

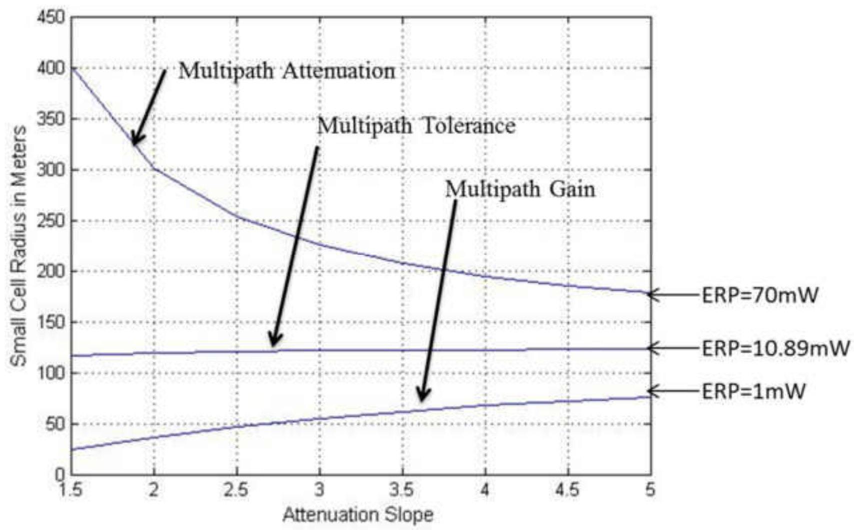

Figure 32. Indoor cell radius as a function of attenuation slope

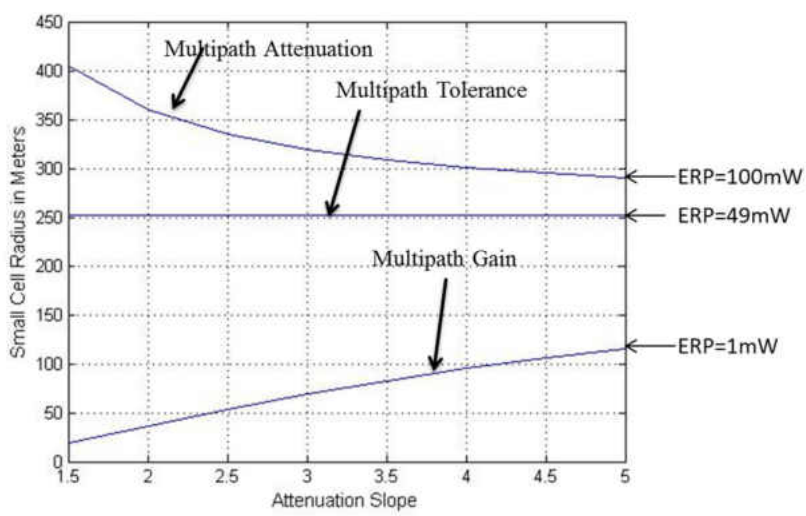

Figure 33. Outdoor cell radius as a function of attenuation slope

When the transmit power is too small, it introduces the waveguide effect (constructive interference), where the reflected and diffracted components are<90 degree out of phase and strong composite signal forms by multiple reflections. The attenuation slope within this condition is less than 2, which means the propagation environment is better than free space.

7.3 Path Profile Analysis

Path profile analysis shows how the signal decays over a distance from base station. The cell site parameters for the path profile analysis are listed in Table 3.

Table 3. Simulation Parameters for Path Profile Analysis in ATOLL

Cell Type	Transmitter height	Operating Frequency	Transmit Power (dBm)
Macro Cell	35m	2100MHz	43Bm
Small Cell	20m	2100MHz	30 dBm

It is found that the radius of Fresnel zone is smaller closer to Macro Cell (shown in Figure 34) but the Fresnel zone radius increases at the cell boundary (shown in Figure 35) due to the signal affected by multipath signal beyond the Fresnel zone breakpoint. As the radius of Fresnel zone increases it becomes more susceptible to shadowing or affected by multipath signal. But in case of Small Cell (shown in Figure 36), the radius of small remains within the first Fresnel zone break point and the transmitted signal is invariant to propagation environment. Since the radius of Small Cell is within a Km, most of the area in dense urban or urban can be covered by Small Cell networks where user will get advantage of line of sight communication. If the users remains within line of sight communication, it can reduce the transmission power and enhance the batter life.

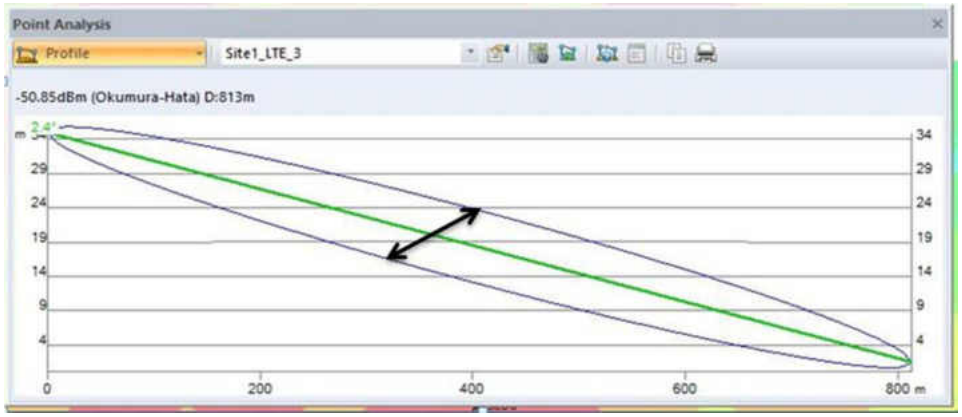

Figure 34. Path profile analysis scenario-1 for Macro Cell.

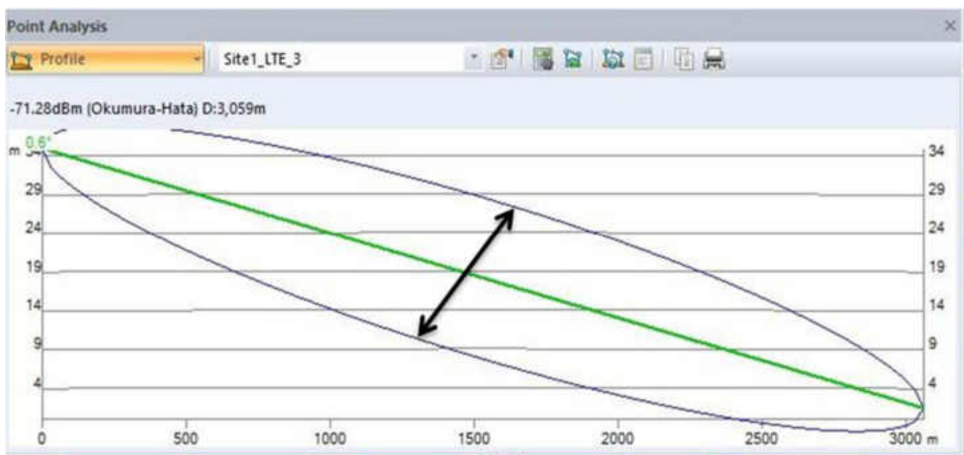

Figure 35. Path profile analysis scenario -2 for Macro Cell

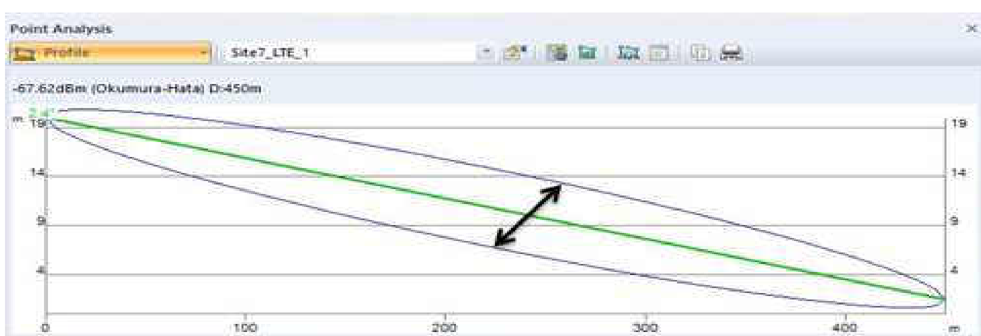

Figure 36. Path profile analysis for Small Cell

7.4 Coverage Analysis of Heterogeneous Networks

Coverage analysis shows how a particular serving area is covered by a network and the analysis of received signal level in that area. After finding the Small Cell radius at 2100MHz for outdoor deployment scenario, seven Small Cell clusters are deployed within and outside of the macro network. The coverage footprints are analyzed for both scenario, Macro Cell only scenario, and with Small Cells by radio network planning tools called ATOLL, shown in Figure 37 and 38. The design consideration and simulation results are shown in below

Table 4. Cell Site Parameters.

Cell Type	Antenna Height	Transmit Power	Cell Radius	Number of UE	Cluster Size
Macro Cell	35m	43dBm	5Km	35 UE per Sector	7
Small Cell	20m	30dBm	840m	10 UE per Cell	4

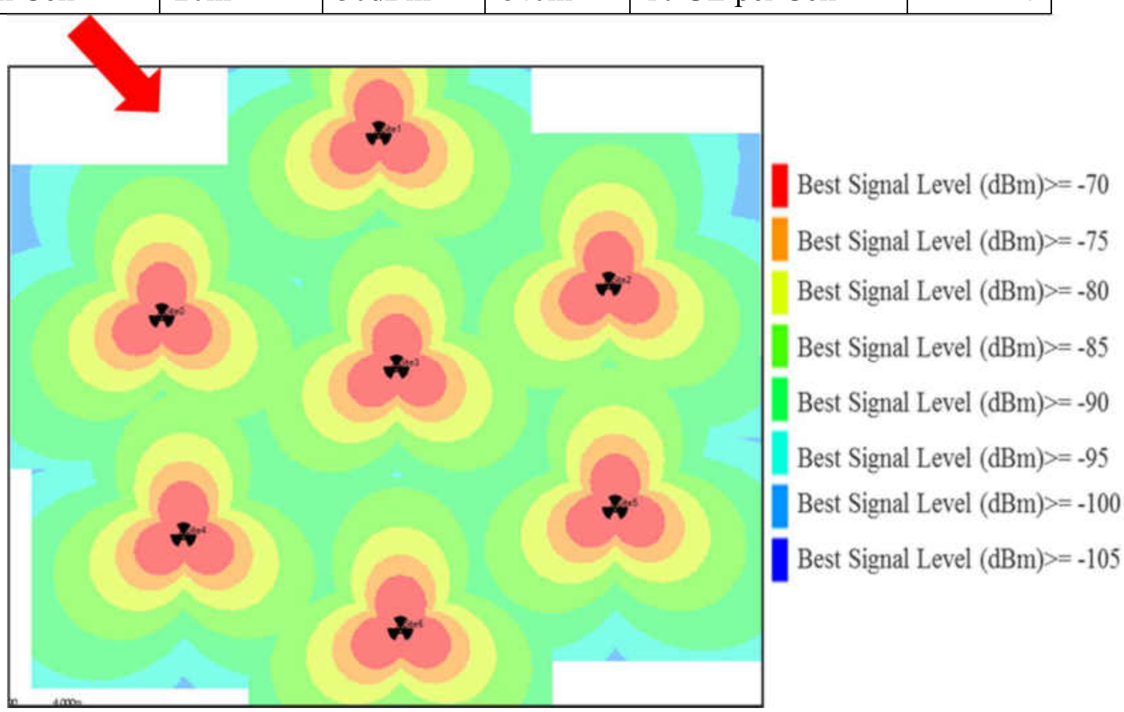

Figure 37. Heterogeneous Networks coverage for Macro only deployment.

In Figure 37 and 38, the different color shows the different signal level. For example, the best signal level shows by red color which is -70dBm and the worst signal is represented by blue which is -105dBm. The received signal is considered as good, if the value is more than -90dBm.In this simulation the area is covered by good quality signal and the cell sites coverage areas are overlapped so that there is no coverage holes in the service area.

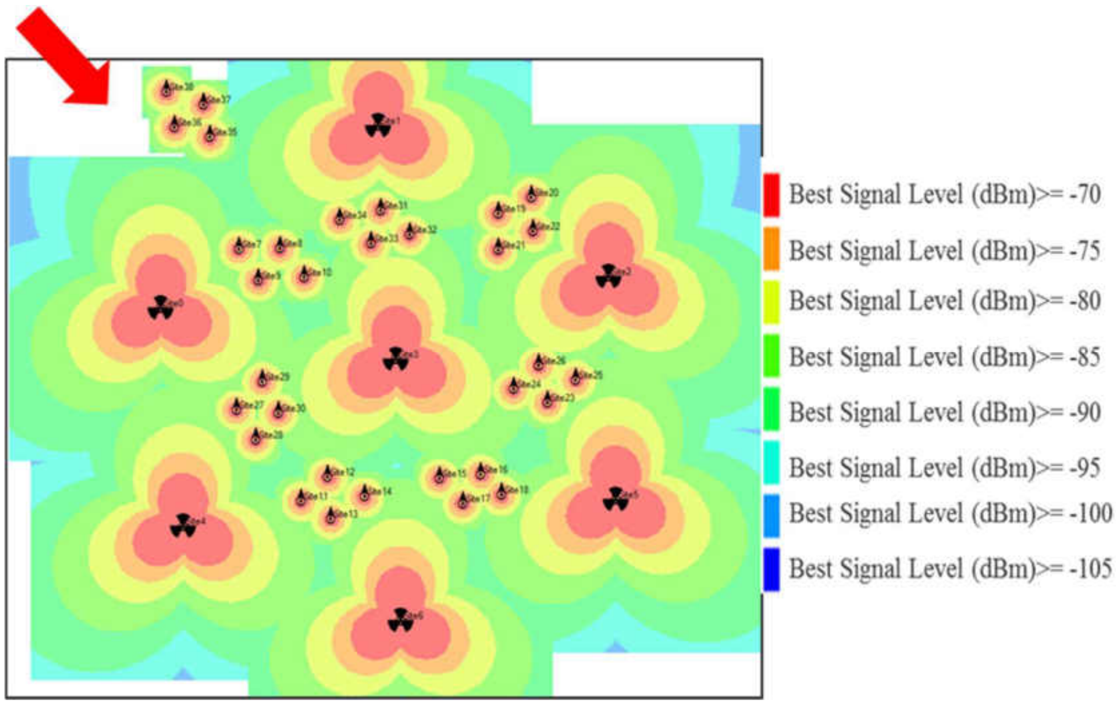

Figure 38. Heterogeneous Network coverage with Small Cell deployment

In figure 37 shows the Heterogeneous Networks coverage considering macro cells only and the figure 38 shows the Heterogeneous Networks coverage with Small Cells. It is found that the signal strength is improved within the macro network by adding Small Cell clusters, and the coverage area is also enhanced as indicated by the red arrow in Figure 38. Although 7 Small Cell clusters are deployed within the macro layer for simplicity, but in case of real deployment scenarios, the number of Small Cell clusters and the size of the clusters is totally depends on the traffic density of the deployment area. So, the operator can customize the Small Cell Deployments based on the traffic demand.

7.5 Capacity Analysis of Heterogeneous Networks

Capacity analysis shows how many users can support by a network for a particular serving area. Similar design consideration is used for capacity analysis and the result is shown in Figure 39 (considering Macro Cell only) and Figure 40 (Considering Small Cells within Macro Cell). The different color in Figures 39 and 40 shows the maximum number of users can support in that area. For example, more than 14 users can support in red areas whereas light blue color area can support less than 11 users.

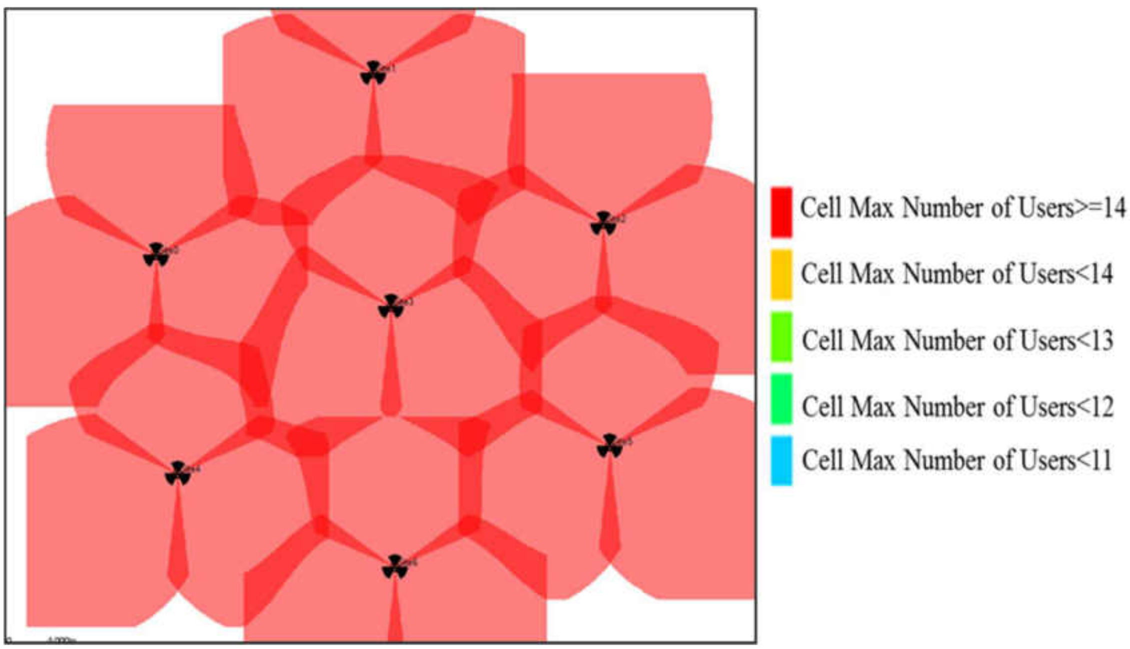

Figure 39. Heterogeneous Network capacity for Macro only (Total users=735)

According to the simulation, Macro only deployment network can support up to 735 users (shown in Figure 39), whereas the capacity increases to 1055 after adding some Small Cell clusters (shown in Figure 40). Although in the simulation 10 users per Small Cell is considered, but this number depends on how much capacity we can support through the backhaul connections. Each Small Cell can support the same amount of traffic as Macro Cell, if we can deliver the enough capacity through backhaul. So, it is clear that adding Small Cells can add more capacity in the network and operator can save energy and cost by deploying Small Cells instead of deploying more Macro cells in the network.

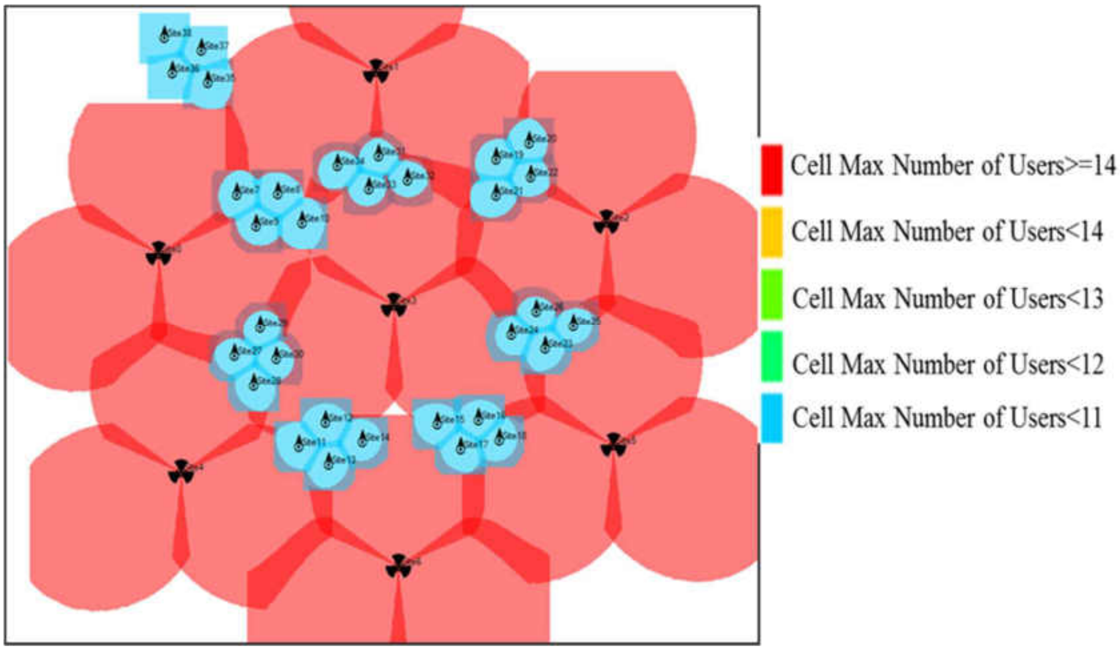

Figure 40. Heterogeneous Network capacity with Small Cell (Total users=735+320=1055)

7.6 Carrier to Interference (C/I) Improvement

In the proposed plan, cochannel interference is greatly reduced that allows frequent reuse of channels, thus enhancing the system capacity. To illustrate this concept, let's consider Figure 8 again, where R is the Small Cell radius and D is the inter-site distance. Since the cochannel site is located beyond the first Fresnel zone breakpoint, the interfering signal at the serving site will suffer multipath attenuation. Thus, the carrier-to-interference (C/I) ratio prediction for six co-channel sites can be modified as [25]

$$\frac{C}{I} = 10Log[\frac{1}{6}\{\frac{D^{(2+\Delta\gamma)}}{R^2}\}] \quad (7.1)$$

Where 2+Δγ is the path loss slope beyond the breakpoint. As shown in Figure.41, the C/I performance is enhanced if R is within the first Fresnel zone breakpoint (e.g., R=840 for f=2100MHz and h2=20m) and the reuse distance is beyond the break point.

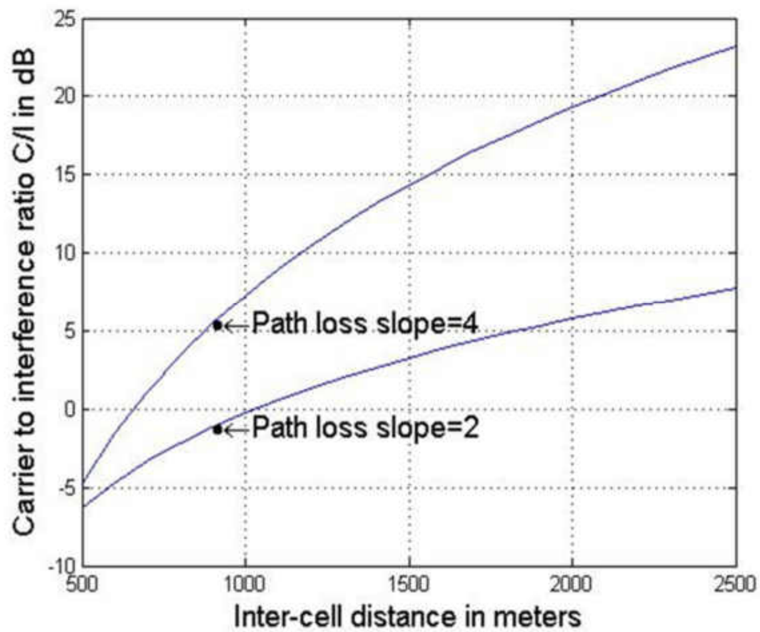

Figure 41. Carrier to Interference for different path loss slope

According to Figure 41, if we would like to deploy cell sites in an urban area, where path lose slope is equal or greater than 4 for Macro Cell but for Small Cell the path loss slope will be equal to 2. So, 6dB carrier to interference gain can achieved by deploying Small Cell, that will further allow adding more Small Cells on the network and enhance the network capacity.

CHAPTER 8

CONCLUSION & FUTURE WORK

It is expected that the mobile data traffic will increase roughly by a factor of 1000 in the next ten years. This thesis presents different approaches to meet the high capacity demand and propose a method to densely deploy the Small Cells within the macro network that boost the coverage and capacity of Heterogeneous Networks. The thesis work findings can be summarized as follows:

a) By utilizing the Fresnel Zone effect proposed a Small Cell architecture where, (i) The cell radius of Small Cells must be within the first Fresnel zone break point, and (ii) The minimum inter-cell distance must be greater than twice of Small Cell radius. The proposed plan greatly reduces the co-channel interference that will allow frequent reuse of channels, thus enhance the system capacity.

b) Propose a new selection and handover method based on path loss slope /attenuation slope value, where a UE (user equipment) select the best cell based on the path loss slope value of the received signal instead receive signal level. It is found that the proposed cell selection method allows dense Small Cell deployment and seamless offloading of traffic from Macro Cell to Small Cell, thus increasing the network capacity without degrading the network quality.

Future work may include the following issues:

a) Since Small Cell can be deployed and maintain by the consumer itself, it will be difficult to maintain the quality of the network in case of dense Small Cell deployment. So more analysis is needed to explore different deployment challenges for dense Small Cell networks and find solutions to minimize the challenges.

b) Analysis the performance of path loss slope based cell selection and handoff method in terms of call drop probability, probability of handoff failure, and ping pong rates.

c) Since the radius of small cell is less than a kilometer, the number of handoff might increase for high speed users. So, more analysis is needed to solve this mobility problem.

APPENDICES

Appendix A

Calculating Fresnel Zone Break Point for Different Antenna height MATLAB™ Code

```
%*******************************************************

%   Thesis_Code_Final

%   Md. Maruf Ahamed

%   University of North Dakota

%   August 2015

% Finding Freznel Zone Breakpoint for different transmitting antenna height

%*******************************************************

clc;

clear;

close all;

h1=1.5; % receiver antenna height

h2=1:5:30; % transmitter antenna height

 f=2100*10^6;

lamda=3*10^8./f;

 d=(4*h1*h2)./lamda % fresnel zone break point in meter

 plot(h2,d)

grid on


xlabel('Transmitting antenna height h2 in meters', 'FontSize', 11);

ylabel('Cell Radius or fresnel zone break point in meter', 'FontSize', 11);

text(3,126,['\bullet\leftarrow' 'd=50, h2=3m'], 'FontSize', 11)

 text(20,840,['\bullet\leftarrow' 'd=294m, h2=20m'],'FontSize', 11)
```

Appendix B
Calculating Fresnel Zone Break Point for Different Operating Frequency MATLAB™ Code

```
%*******************************************************

%   Thesis_Code_Final

%   Md. Maruf Ahamed

%   University of North Dakota

%   August 2015

% Finding Fresnel Zone Break Point for Different Operating Frequency

%*******************************************************

clc;

clear;

close all;

h1=1.5; % receiver antenna height

h2=3; % transmitter antenna height for outdoor

 f=400*10^6:500*10^6:5900*10^6;

%f=1700*10^6;

lamda=3*10^8./f;

 d=(4*h1*h2)./lamda % fresnel zone break point in meter

 plot(f,d)

grid on

 xlabel('Operating frequency in Hz', 'FontSize', 11);

ylabel('Cell Radius or fresnel zone break point in meter', 'FontSize', 11);
```

```
text(2100*10^6,126,['\bullet\leftarrow' 'f=2100MHz, d=126'], 'FontSize', 11)

text(3500*10^6,210,['\bullet\leftarrow' 'f=3500MHz, d=210'],'FontSize', 11)
```

Appendix C

Multipath Effect in Proposed Small Cell Planning MATLAB™ Code

```
%*****************************************************

%   Thesis_Code_Final

%   Md. Maruf Ahamed

%   University of North Dakota

%   August 2015

% Multipath Effect in Proposed Small Cell Planning

%*****************************************************

clc;

clear;

close all;

h1=3; %transmitting antenna height in meter

h2=1.5; % receiving antenna height in meter

f=2100; % operating frequency in MHz

d=(4*h1*h2*f*10^6)/(3*10^8) % fresnel zone break point

RSL=-100;% -70dBm=-70-30=-100dB , Desired Received signal level in dB

ERP=10*log10(10.89/1000); % ERP in dBW

Lp=32.44+20*log10(f)+20*log10(d/1000)

gama=1.5:.5:5;

 exp=(ERP-Lp-RSL)./(10*gama)
```

```
D=d*10.^(exp)
 plot(gama,D)
grid on


hold on
 ERP=10*log10(70/1000); % ERP in dBW
Lp=32.44+20*log10(f)+20*log10(d/1000)
gama=1.5:.5:5;
 exp=(ERP-Lp-RSL)./(10*gama)
D=d*10.^(exp)
 plot(gama,D)
 hold on
 ERP=10*log10(1/1000); % ERP in dBW
Lp=32.44+20*log10(f)+20*log10(d/1000)
gama=1.5:.5:5;
 exp=(ERP-Lp-RSL)./(10*gama)
D=d*10.^(exp)
plot(gama,D)
xlabel('Attenuation Slope', 'FontSize', 11);
ylabel('Small Cell Radius in Meters', 'FontSize', 11);
```

Appendix D

Carrier to Interference Analysis MATLAB™ Code

```
%*******************************************************

%   Thesis_Code_Final

%   Md. Maruf Ahamed

%   University of North Dakota

%   August 2015

% Carrier to Interference Analysis for different deployment areas

%*******************************************************

clc;

clear;

close all;

%gama=1:.5:4.5; % 2=free space, 2.5=rural, 3=suburban, 3.5=typical urban,4=Dense
Urban

gama=2;

gama2=4; % for dense urban

j=6;

R=420; %for 700MHz LTE, h1=30m, h2=1.5m radius of smll cell

D=500:100:2500  ;%for directional reuse, interferer is 2

 CtoI=10.*log10((1./j).*((D./R).^gama))

CtoI2=10.*log10((1./j).*((D./R).^gama2))

 plot(D, CtoI)

grid on

xlabel('Inter-cell distance ', 'FontSize', 11);
```

```
ylabel('Carrier to interference ratio C/I', 'FontSize', 11);
 hold on
 plot(D, CtoI2)
xlabel('Inter-cell distance in meters', 'FontSize', 11);
ylabel('Carrier to interference ratio C/I in dB', 'FontSize', 11);
 text(900,-1.162,['\bullet\leftarrow' 'Path loss slope=2'],'FontSize', 11 )
text(900,5.458,['\bullet\leftarrow' 'Path loss slope=4'], 'FontSize', 11)
```

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