JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

INDOOR RADIO NETWORK PLANNING:COVERAGE AND CAPACITY PLANNING OF SMALL CELLS FOR BUILDINGS

By

Mantegbosh Awoke Birhanea

This thesis is submitted to School of Graduate Studies of Jimma University in partial fulfilment of the requirements for the degree of
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Abstract

Indoor Radio network planning has been a long-standing problem since the very starting commercialization and business of indoor mobile communications system ,of which power coverage and capacity coverage are the two major objectives.Indoor RNP of a new Radio interface such as Small cell LTE needs new tools and competencies.The introduction of pico cell and femto cell driven small cell technology and comparison of pico cell and femto cell, in small cell technology ,makes network planning challenging.

In this work,coverage and capacity estimation of pico cell and femto cell network was performed for future network deployment.Our designed network femto cell were improved by 12.23% and pico cell by 9.06%.Femto cell network coverage and capacity is best as compared to pico cell network .In the case of coverage planning,Radio link budget together with important link level simulations was performed to determine path loss.Comparison of path loss models were used to select the best model.

A COST Multiwall winprop path loss model was used to determine the cell radius per morphology.For capacity evaluation,data rate,throughput analysis,and important system level simulations was performed to know subscribers supported per site.Cell edge throughput and Receiver Sensitivity was determined as the measure of performance and effectiveness for capacity analysis.

Finally,coverage target number of sites,capacity target number of sites,and the final limiting site count was determined.

Keyword: ***Indoor Radio network planning, small cells, coverage, capacity, radio wave propagation***

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Abbreviations

AP	**A**cess **P**oint
BSC	**B**ase **S**tation **C**ontroler
CDMA	**C**ode **D**ivision **M**ultiple **A**ccess
CN	**C**ore **N**etwork
CSG	**C**losed **S**ubscriber **G**roup
DAS	**D**istribute **A**ntenna **S**ystem
ENodeB	**E**nvolved **N**ode **B**ase tranciever station
EPC	**E**nvolved **P**acket **C**ore
E-UTRAN	**E**volved **U**MTS **T**errestrial **R**adio access network
FAP	**F**emto cell **A**ccess **P**oint
FMC	**F**ixed **M**obile **C**overage
GSM	**G**lobal **S**ystem **M**obile
HetNet	**H**etrognous **N**etworks
IEEE	**I**nstitute of **E**lectrical and **E**lectronics**E** ngineers
IMT	**I**nternational**M**obile **T**elecommunication
ITU	**I**nternational**T**elecommunication **U**nion
LOS	**L**ine**O**f **S**ite
LTE-A	**L**ong **T**erm **E**volution advanced
MAPL	**M**aximum**A**llowed**P**ath**L**oss
Mbps	**M**egabits**p**er **s**econd
MIMO	**M**ulti**I**nput **M**ulti **O**utput
NLOS	**N**one **L**ine **O**f **S**ite
MKM	**M**ely**K**eenan **M**odel
MWM	cost-Multi**W**all **M**odel

OFDM	**O**rthogonal**F**requency **D**ivision **M**ultiple access
PAPR	**P**eak to **A**verage **P**ower Ratio
PDSCH	**P**hysical**D**own Link **S**hared **CH**annel
PUSCH	**P**hysical **U**plink **S**hared **CH**annel
PRBs	**P**hysical **R**esource **B**locks
QAM	**Q**uadrature**A**mplitude **M**odulation
QOE	**Q**uality **O**f **E**xperience
QOS	**Q**uality **O**f **S**ervice
QPSK	**Q**uadrature **P**hase **S**hift **k**ey
RAN	**R**adio **A**ccess **N**etwork
RBs	**R**esource **B**locks
RF	**R**adio**F**requency
RNP	**R**adio **N**etwork **P**lanning
RSRP	**R**eference **S**ymbol **R**eceived **P**ower
RSSI	**R**eceived **S**ignaL **S**trength **I**ndicator
SINR	**S**ignal to **I** nterference and**N**oise **R**atio
SDM	**S**pace **D**ivision **M**ultiplexing
TDD	**T**ime **D**ivision **D**uplex
TxPWR	**T**ransmitted**P**ower
UE	**U**ser **E**quipment
UMB	**U**ltra **M**obile **B**roadband
UMTS	**U**niversal **M**obile **T**elecummunication **S**ystem
VoIP	**V**oice **O**ver **I**nternet **P**rotocol
WI-MAX	**W**orldwide for**I**nteroperability **M**icrowave **A**ccess

Chapter 1

Introduction

1.1 Background

As we are moving from second generation to third and fourth generation networks voice and data demand is increasing and due to this fact demand for wireless infrastructure had become prominent .Indoor coverage is gaining importance in today's world, as most of the voice traffic is generated by the indoor users according to a research that 80% of the traffic is generated by the indoor users [1]. There are a tremendous amount of challenges from business and technical perspectives that are considered when one is planning and implementing indoor coverage that should focus future proof solutions. For indoor radio planners it is essential that they should not only focus on the technical challenges ahead but they should try to fill in the room of any need that is going to come in their way in future [1].
Indoor coverage is normally provided by outdoor macro cell. In contrast to macro cells Femto/Pico cells solutions are also available which could be used. A Femto cell is a small cellular base station, typically designed for use in a home or small business [2] whereas A pico cell is a wireless communication system typically covering a small area, such as In-building (offices) or more recently in-aircraft [3].Femto cells are preferred to be used in those places which have a limited setup like in small offices environment which have limited number of users in this way power

consumption by the base station could be scaled down. Pico cells are used as an alternative where Femto cells fails to provide full coverage and capacity requirements.

Why in building coverage is important:There are many factors that are dependent both on technical and commercial bases that makes indoor coverage really important Some of the reasons that make indoor coverage really important are, to increase the coverage capacity so reduce the network load on existing macro outdoor network,to offer higher data rates to the users. In fact above mentioned facts are important but before we deploy any sort of indoor network it is really important that you should evaluate building thoroughly, that which type of deployments is feasible, and what should be the cost per user etc. These factors are considered in business evaluation. This sort of evaluation is normally carried out by using standard tools, templates and metrics in order to secure valid comparable business case.

Indoor coverage business point of view:When considering the case for femto cell , power load per user is an important factor. The higher the power drain from the base station the higher the capacity drain from the base station per mobile user will be [1],[4]. As a result there will be high production cost for indoor traffic for femto cell trying to accommodate users inside the building by using the femto base station from inside[1]. On the other hand there is one more factor that should be considered. By the help of in building coverage we can reduce the production cost per call minutes or MB and can also reduce the noise increase in the network. According to the estimate by using the In Building coverage there would be a reduction of about 50%-70% on production cost per call per minutes [1].

Small cells offer several benefits. These include i) over two orders of magnitude increase in overall capacity, ii) cost-effective coverage extension, and iii) Green radio solution. Small cells vary between each other in several ways including coverage area, physical size and backhaul technology and can be utilized for both indoor and outdoor deployments.

In general, there are four common deployment configurations for small cells: Residential deployment: Typically, for this case, small cells operating with low-power and short range such as femtocell base stations are utilized. The major attributes of this type of small cells is their Internet-based backhaul, low power consumption, self-organization and optimization and robust deployment [2].

Enterprise deployment: This constitutes the deployments within large office buildings or in public indoor areas such as airports. Both femtocell and Pico cell base stations are adopted for enterprise deployments. When femtocells are utilized, it is common to deploy a number of femtocells with self-organizing features. In this case, the deployment within the enterprise may be planned but it need not require careful RF planning with the rest of the cellular network. However, Pico cells which have a relatively larger coverage area than the femtocells need careful radio frequency planning before they are deployed. The incorporation of self-organizing features in Pico cells can facilitate flexible deployment. In addition, the Pico cells typically feature dedicated backhaul (wired or wireless) unlike the IP backhaul utilized by femtocells.

Outdoor urban deployment: For the particular case of outdoor urban or metropolitan areas, metro cells are utilized to provide capacity enhancements as well as coverage to areas that experience large losses from macrocell due to shadowing. Metro cells are typically mounted on building walls, lamp posts, etc.

Outdoor rural deployment: For rural areas, the key objective is to provide coverage over large areas not served by the macrocell. In this case, microcells are utilized which have a substantially large coverage area compared to the Pico cells and femtocells. However, the lack of infrastructure may result in incorporating LOS/NLOS wireless backhauls for these microcells. However, microcells may also be present in large cities for addressing the capacity needs.

A huge network of cell sites called macro base stations handles cell-phone traffic. With their high power, tall towers with multiple antenna arrays, long range, and backup power sources, macro base stations cover most of the area. Finding and securing suitable locations for base stations is getting increasingly difficult,though. The solution is the small cell.

In addition, the success of the smart phone and the growing subscriber demand for more and faster service are pushing cellular carriers to expand and upgrade their base station deployments. The carriers responded by upgrading their systems with 4G Long Term Evolution (LTE), which offers significantly faster download speeds demanded by the major increase in video consumption. LTE is still being installed with full coverage not expected for several more years. One clear solution is the LTE small cell. The ultimate limit is the spectrum available to the carrier. Again, small cells can provide an interim solution until more spectrum is freed up.

Another major issue for cell phones is indoor performance. More than 80% of all cell-phone calls occur in homes, offices, shopping malls, hotels, and other indoor venues [1],[5]. Indoor performance is significantly poorer than outdoor performance since the radio signals are seriously attenuated, distorted, and redirected by walls, ceilings, floors, furniture, and other obstacles [1]. Indoor situations limit the range of the radio and greatly curtail data speeds. LTE is helpful in overcoming this problem, but the real solution is the small cell.

As it turns out, public and private Wi-Fi hotspots and access points fit the basic definition of a small cell. They can connect to a user smart phone, tablet, or laptop and provide access to video and other information and media demanded by the user. We don't have to use the cellular network to download video or access other big data applications if a Wi-Fi hotspot is nearby. Most cellular small cells will include a Wi-Fi access point. Groups of physically small cells can be installed anywhere, indoors or out. They can sit on a desk or be mounted on a wall, roof, lamppost, or light pole. The small cells fill in the gaps in coverage and provide service where macro cell coverage is poor.

There will be from five to 25 small cells per macro cell in most networks. Networks of small cells overlay, or as some say underlay, the macro network to provide an overall boost not only in data speeds but also subscriber capacity. The general customer performance is greatly improved with more reliable connections and significantly higher download speeds. Distributed antenna systems (DASs) also are part of the small-cell trend. They use fiber-optic cable from a macro base station to an array of antennas spread over a wide area to extend the reach and improve connection reliability. DASs are used in large buildings, airports, convention centers, and other large public venues. They could potentially be used to extend the range of small cells as well. Collections of macro base stations, small cells, Wi-Fi hotspots, and DASs are known as heterogeneous networks, or HetNet.

All small cells use the existing licensed spectrum assigned to the carrier's networks. The limited spectrum is shared by frequency reuse and spatial diversity. Frequency reuse refers to the use of the same band by multiple cell sites. Spatial diversity means that these sites are spaced from one another so coverage areas do not overlap and power levels are controlled to eliminate or minimize interference with adjacent cells and with those on the same frequency. On the most basic level, small cells are low-powered radio access nodes, with a range of a few meters to a mile in diameter. There are three types of small cells, and ranging from smallest to largest they are called femtocells, Pico cells, and microcells. As a class, they are considered "small" compared to a mobile microcell, which can have a range of about 20 miles.

The various types of small cells have various applications.

Macro cell is a cell used in cellular networks with the function of providing radio coverage to a large area of mobile network access. A macro cell differs from a microcell by offering a larger coverage area and high-efficiency output. The macro cell is placed on stations where the output power is higher, usually in a range of tens of watts.

Microcells are difficult to precisely distinguish from Pico cells, but their coverage area is the prime delineator. Microcells can cover areas less than a mile in diameter and uses power control to limit this radius. Microcells can be deployed temporarily in anticipation of high-traffic within a limited area, such as a sporting event, but are also installed as a permanent feature of mobile cellular networks.

Pico cells offer greater capacities and coverage areas, supporting up to 100 users over a range of less than 250 yards. Pico cells are frequently deployed indoors to improve poor wireless and cellular coverage within a building, such as an office floor or retail space.

Femtocells are typically user-installed to improve coverage area within a small vicinity, such as home office or a dead zone within a building. Femtocells can be obtained through our mobile operator or purchased from a reseller. Unlike Pico cells and microcells, femtocells are designed to support only a handful of users and is only capable of handling a few simultaneous calls.

Small cells are fully featured, short range mobile phone base stations used to complement mobile phone service from larger macro cell towers.The term femtocell was originally used to describe residential products, with Pico cell being used for enterprise/business premises and metro cell for public/outdoor spaces. These range from very compact residential femtocells, the size of a paperback book and connected using standard domestic Internet broadband through to larger equipment used inside commercial offices or outdoor public spaces. They offer excellent mobile phone coverage and data speeds at home, in the office and public areas for both Voice and data. Small cells have been developed for both 3G and the newer 4G/LTE radio technologies.

As the underlying femtocell technology expanded to address this wider scope, the term small cell was adopted to cover all aspect. Small cells can be applied in a number of situations, ranging from single rooms or houses in a residential scenario to urban and rural deployments. The enterprise and urban areas are driven by both coverage and capacity, while rural and residential areas are driven mostly by coverage [1]. DAS combined with Pico Cells is applicable in both urban and

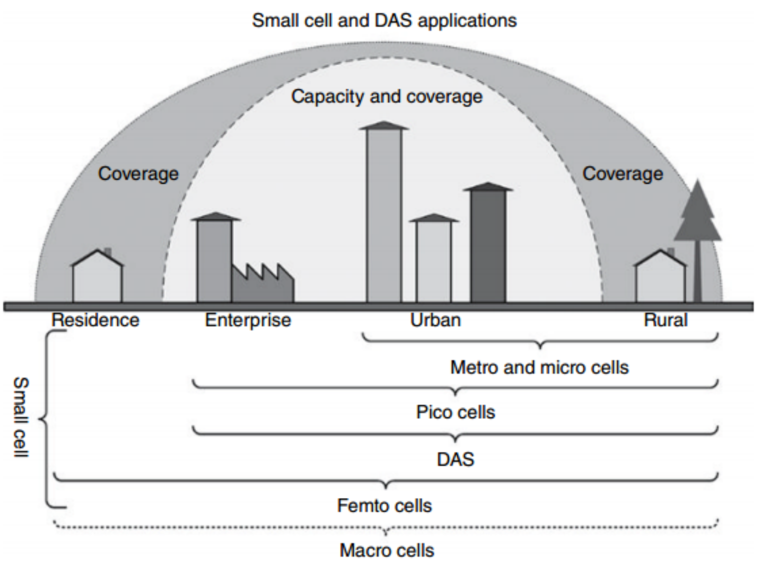

FIGURE 1.1: Small cells, Femto, Pico and Micro cells

rural/suburban deployments (for outdoor DAS deployment). Small cells will typically be deployed to solve coverage issues in residential and rural areas and in enterprise and urban applications will typically be implemented to increase capacity, and often close coverage gaps in the network as well. Due to this application small cell indoor radio network planning is very important for indoor users and would be considered the building coverage and capacity during planning.

1.2 Statement of the Problem

There are numerous challenges, both from a business and a technical perspective, when designing and implementing indoor coverage solutions. Indoor radio planners carry a major responsibility for the overall business case and performance of the network. In many countries 80% of users are inside buildings, and providing high performance indoor coverage, especially on higher data rates, is a challenge [1]. It is much more than a technical challenge; the Business case must also be evaluated, as well as future proofing of the solutions implemented, among other considerations.

Let us explored some of the challenges for the macro coverage penetrating deep inside buildings and providing sufficient coverage and service level where the users are located. In urban and suburban environments macro coverage will typical reach the users by reflection and diffraction through multipath propagation [1]. The delay profile will typical be 1 to 2 Micro second. Only a minor part of the traffic is serviced by the direct signal in line of sight to the base station antenna, having only the free space loss plus penetration loss of the building. In most or all cases the resulting signal at the receiver will be a result of the multipath radio channel a 'mix' of different signals with different delays, amplitudes and phases. The result is a multipath fading signal with a fading pattern that mainly depends on the environment and the speed of the mobile. Surprisingly, very often a building with a macro site on the roof can have coverage problems at the core of the same building, especially on the lower floors of the building and near the core.

This peculiar problem occurs due to the fact that coverage inside the building relies on Reflections from adjacent buildings. On the topmost floors the coverage might be perfect, but the further down, problems starts to occur. Starting with lack of coverage in the staircase and in the elevators, in many cases the inner core of the building might have performance problems, especially with data service. If a building with the rooftop macro has no, or only low, adjacent buildings, this problem can be a major issue, due to the lack of buildings to reflect the signal back into the servicing Building. However the problem can be easily solved by deploying a small indoor solution, filling in the black spot. When providing radio coverage for mobile users inside buildings, they are facing several radio planning challenges. It is mainly these challenges that motivate the need for indoor coverage solutions.

1.3 Objectives of the Research

1.3.1 General Objective

The general objective of this thesis is planning small cells indoor radio network coverage and capacity for buildings by using indoor radio network planning tools.

1.3.2 Specific Objectives

- To compare indoor radio network planning path loss model
- To analyze the impact of base station sites on coverage and capacity planning.
- To define indoor radio network planning tools.
- To perform coverage and capacity planning in terms of power,path loss, field strength,SNIR,Data rate and throughput for each site.

1.4 Methodology

Small cell is a new technology, largely in the state indoor radio network planning for building. This means that it is very essential to get many services with high data rate and Mostly, 3GPP standardization documents and drafts have to be relied up on.

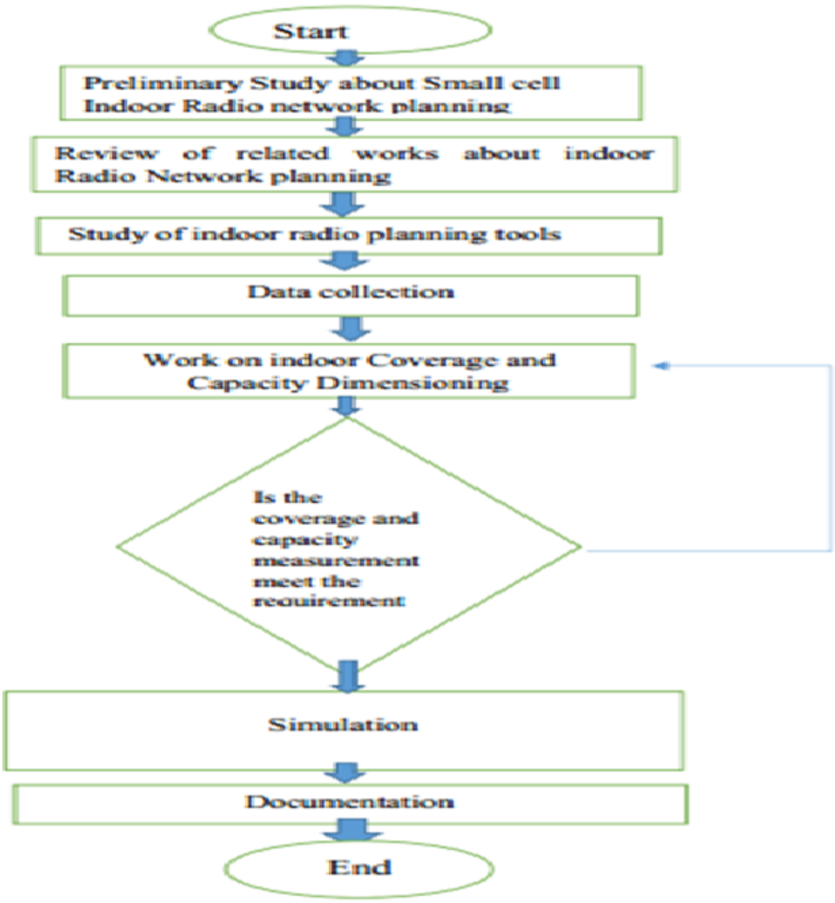

FIGURE 1.2: General Block diagram for the research

1.5 Significance of Thesis

The indoor radio network planning of small cells needs extensive assessment in terms of capacity, coverage and quality requirements. The ultimate objectives of studying small cells indoor radio network planning are to introduce relevant small cells features, to define the basic models for indoor radio propagation, to estimate coverage and network count.Hence the capacity and coverage would be based on simulation of the proposed techniques using Indoor Radio Network planning tool in the area of small cell indoor radio network and for this thesis, only focus the radio network dimensioning for femto cell indoor technology based on Auto cad data base Building area would be studying.

1.6 Thesis Outline

This thesis consists of seven chapters. Chapter 1 introduces some background information, followed by statement of the problem, objectives of the thesis, methodologies and significance of the thesis. Chapter 2 introduces indoor radio network planning and some literature reviews relevant for this work. Chapter 3 deals with general overview of Small cells indoor radio network planning technologies. This includes basics of macro cell, micro cell, Pico cell, femto cell technologies and their features related to network dimensioning.

Chapter 4 explains the main thesis body: Indoor radio network planning. This chapter covers the radio link budget calculation, coverage dimensioning, propagation model selection and the method to calculate the number of sites based on the coverage. It describes also the capacity planning for femto cell LTE Network elaborating the methods used and factors impacting the capacity planning process. And it explains the frequency planning for femto cell Network with particular attention on femto cell LTE 1800MHz allocation, besides Cell throughput calculation, traffic demand estimation and air and access network dimensioning are derived in this chapter.

Chapter 5 relates to indoor radio network planning tool. It explains the structure and functionalities of the software and discusses the prediction and performance results of the designed network. Chapter 6 conclude the thesis with summary of the entire thesis work and possibilities of future research.Chapter 7 The appendix including the matlab code with simulation parametrs.

Chapter 2

Litrature Review

2.1 Introduction to Radio Network Planning

In recent years, a substantial increase in the development of broadband wireless access technologies for evolving wireless Internet services and improved cellular systems has been observed. Because of them, it is widely foreseen that in the future an enormous rise in traffic will be experienced for mobile and personal communications systems. This is due to both an increased number of users and introduction of new high bit rate data services. This trend is observed for Small cells fourth-generation systems, and it will most certainly continue for fifth-generation systems.

There have been several works done on the area of GSM, UMTS and LTE dimensioning and Planning. Some of the recently published articles related to this work are reviewed as follows: Yiming Sun, 2004 [6]: Radio Network Planning for 2G and 3G deals with the procedure of How to carry out the radio network planning for 2G and 3G systems. The general steps and methods for wireless radio network planning are first addressed. Then the issue of radio network planning is discussed with special focus on the 2G and 3G networks, as well as a comparison between 2G and 3G radio network planning processes which is summarized at the end.

Reshma Begum Shaik, T.Krishna Chaitanya, 2012 [7]: Simulation of GSM Mobile

Networks Planning Using ATOLL Planning Tool, International Journal of Engineering and Innovative Technology (IJEIT). we showed that planning of GSM networks with ATOLL. Anteneh Temesgen, 2015 [8]: WCDMA Radio Network Dimensioning and Planning for the Case of Bahir Dar City. Covers WCDMA radio coverage and capacity dimensioning and Planning.Took demographic data for capacity estimation and considered cell load and Calculated throughput in detail for capacity dimensioning.

A.Benjamin Paul and Sk.M.Subani, 2012 [9]: Code Planning of 3G UMTS Mobile Networks Using ATOLL Planning Tool", International Journal of Engineering Research and Technology (IJERT). This paper involves on simulation exercise on planning of 3G UMTS network with the Help of Atoll planning software tool. It involves planning of coverage, quality and capacity of UMTS Network which uses WCDMA in radio interface between 3G base station and the User equipment. It also involves planning of scrambling codes for 3G WCDMA Network. Abdul Basit, Syed, 2009 [10]: Dimensioning of LTE Network Description of Models and Tool, Coverage and Capacity Estimation of 3GPP Long Term Evolution radio interface. This thesis Covers coverage and capacity estimation in radio network dimensioning. Radio link budget is used To investigate coverage planning. He used excel based dimensioning vendor tool which is designed for the usage of vendor. This can't assure weather the important parameters are considered. Basanta Shrestha, 2010 [11]: In this thesis an attempt to provide analysis of LTE system Performance from radio network planning aspects has been made. Determination of simulation Results has been obtained and the effect of change in number of transmitting antennas special focus On MIMO techniques has been shown in detail.

Liang Zhang, 2010 [12]: Network Capacity, Coverage Estimation and Frequency Planning of 3GPP Long Term Evolution, Linköping University Master Thesis. In this thesis, the capacity of The LTE network is depicted with the indicators of average transmission data rate, peak transmission data rate and the subscriber's numbers supported by the system. The coverage of the LTE system is also calculated on the base of base station parameters and different propagation Models. The theoretical work of this thesis was implemented in WRAP software and by

using WRAP's capacity calculation and evaluation tools, estimation and optimization of an LTE network was performed.
Bethelhem Seifu, 2012 [13]: LTE Radio Network Planning: Modeling Approaches for the Case of Addis Ababa. This thesis covers coverage and capacity dimensioning and RAN nominal Planning of LTE networks.And also used Mat lab 2008b as a simulation environment for analysis. The Planning didn't use the digital map of the area and she specifies as a limitation about the number Of user in that area are not known and here is the main drawback of her thesis.
Marwa Elbagir Mohammed and Khalid Hamid Bilal, 2012 [14]: LTE Radio Planning Using Atoll Radio Planning and Optimization Software", International Journal of Science and Research (IJSR). They carried out coverage and capacity estimation in radio network dimensioning. Radio Link budget is investigated for coverage planning.
Bekele Mulu, 2013 [8]: Dimensioning and Planning of LTE Radio Network for Future Deployment in Bahir Dar City. It covers LTE radio coverage and capacity dimensioning and planning, however the simulation results showed that it was not done based on the calculated cell Radius and he did not use computational zone for his planning area. In addition he has not covered Physical cell identity planning.
Rakibul Islam Rony,2013 [15]:Small Cells for Broadband Internet Access in Low-Income Suburban Areas in Emerging Market Environments.It covers the small cells inluding femto cells.But did not consider the calculated emprical models and did not done the link budget calculation for coverage and capacity planning.
Hamit Taylan Yüce,2018 [16]:A Planning and Optimization Framework for Hybrid Ultra-Dense Network Topologies. It covers the planning of small cells,however the simulation results showed that it was not done based on calculated path loss model and did not use win prop-tool to determine the coverage. There are also technical literature and periodic reviews that deal heavily with future coexistence of 2G, 3G and 4G. Especially Wireless World research Coexistence of GSM, HSPA/WCDMA And LTE, 4G Americas, multi RAT planning and 3GPP standards are the literatures that helps us in planning Small cells indoor Radio network planning, like

femto cell LTE by calculating link budget, by offloading macro cell network inside building, by using indoor radio network planning tool win prop and it had not been reported in literatures before.

Chapter 3

Small cells Indoor Radio Network Technologies Over View

3.1 Small Cell Cellular Network

A cellular network is a radio network distributed over land through cells where each cell includes a fixed location transceiver known as base station. These cells together provide radio coverage over a larger geographical area. Thus, principal of cellular systems is to divide a large geographic service area into cells with diameters from 2 to 50 Kms, each of which is allocated a number of radio frequency (RF) channels. Today's cellular networks give subscribers advanced features over alternative solutions, including increased capacity, small battery power usage, a larger geographical coverage area and reduced interference from other signals. Popular cellular technologies include the Global System for Mobile (GSM) communication, General Packet Radio Service (GPRS), 3GSM and Code Division Multiple Access (CDMA) [17]. Some of the advantages of cellular systems with small cells are:-"

3.1.1 Advantages of Cellular Systems with Small Cells

- Higher Capacity: "Implementing Space Division Multiplexing (SDM) allows frequency reuse. If one transmitter is far away from another i.e. Outside the interference range, it can reuse the same frequencies. As most mobile phone systems assign frequencies to certain users (or certain hopping patterns), this frequency is blocked for other users" . But frequencies are a scarce resource and the number of concurrent users per cell is very limited. Huge cells do not allow for more users. On the contrary, they are limited to less possible users per km. This is also the reason for using very small cells in cities where more people use mobile phones.

- Low transmission power: While power aspect is not a big trouble for base stations, but they are indeed problematic for mobile stations. A receiver far away from a base station need more transmit power than the current few Watts. But energy is a serious problem for mobile handled devices.

- Local interference: Besides, local interference, the long distances between sender and receiver results in even more interference problems. With small cells, mobile stations and base stations operators only have to deal with 'local' interference.

- Robustness: Cellular systems are decentralized. So, are more robust against the failure of single components. If one antenna fails, this only influences communications within a small area. There are some disadvantages of small cell cellular networks also, and it will be desirable to mention them also:

3.1.2 Disadvantages of Cellular Systems with Small Cells

- Infrastructure needed: Cellular systems need a complex infrastructure to connect all base stations. This includes many antennas, switches for call forwarding, location registers to find a mobile station etc., which makes the whole system quite expensive.

- Handovers increased: The mobile station has to perform a handover whenever there is a change from one cell to another. Depending on the cell size and the speed of movement, this can happen quite often.
- Frequency planning: To avoid interference between transmitters using the same frequencies, frequencies have to be distributed carefully. On one hand, interference should be avoided on other hand only a limited number of frequencies are available.

Small cells are low cost and low power base stations that have shorter coverage area relative to macro base stations. Small cells can be deployed both indoors and outdoors. Small cells are used for offloading macro traffic or to complement macro cell capacity in very dense areas. Small cells are being deployed in coordination with macrocell forming heterogeneous networks.

A drawback of heterogeneous networks is expensive backhaul. Small cells are classified as femtocells, Pico cells and microcells. Generally, femtocells support a range of 10-50 m, Pico cells support a range of 200 m, and microcells support a range of 2 km. Femtocells are deployed indoors and can be user-deployed or operator deployed. Pico cells and microcells can be deployed indoors and outdoors and are mostly operator-deployed to usually improve outdoor to indoor coverage. The most important to the micro-operator concept are femtocells and Pico cells as these lead to significant increase in indoor capacity and coverage and are simple plug-and-play devices. Another advantage is that they utilize user's existing network as backhaul and being indoor deployments, they can better guarantee sufficient indoor coverage and low latencies.

The studies show better performance indoors with use of femtocells [18] and comparison of Pico cells and Wi-Fi densification [19] shows that in the long run small cells will be cheaper and more beneficial.Regardless of whether it is a small cell or macrocell the average throughput in all cases is the same, given the channel bandwidth and number of sectors is the same. As the size of the cell reduces, the capacity in the area increases because capacity is inversely related to radius of the cell. So, in an ideal situation if 4 small cells with half the radius of a macrocell are deployed, then the capacity is quadrupled.

Although the capacity increase will depend on a lot of factors such as wall penetration losses, user mobility and distribution, fading etc. but it is safe to assume that capacity increase will be on the order of the number of small cells deployed. Also, the users in campuses and enterprises are located closer to access points and with lower mobility there should not be a problem in keeping this capacity assumption. Femtocells are the best candidate for in-building high capacity deployments with low mobility of users, as the cell radii are smallest and capacity increase can be the highest. Whereas, if it were a combination of fast moving users and vehicles in the outdoor campus area a combination of Pico cells with femtocells can be used. Placing multiple Pico cells with higher power, close to each other will cause higher interference than femtocells which can be placed closer with lesser interference.

Currently, a lot of campus and enterprise networks have Wi-Fi already deployed but it doesn't offer the QoS offered by 3GPP cellular solutions. Wi-Fi deployments will continue to exist and can be a great way to reduce costs further with interworking between femtocells and Wi-Fi. There are differences in IEEE and 3GPP standards.

The standardization of these is not there yet but it is expected that they would be employed in the future since they utilize unlicensed spectrum and can provide significant improvements in coverage and capacity without higher costs. If future requirements of 100 Mbps data rate available per user and this will be possible by going towards higher frequencies and using wider bandwidths. That is double that of 4G are possible for 5G [20].

Small cells as an "umbrella term for operator-controlled, low-powered radio access nodes, including those that operate in licensed spectrum and unlicensed carrier-grade Wi-Fi [21],[22],[23]." A small cell is usually thought to be a femtocell, Pico cell, metro cell or microcell, all of which are concepts for small-scale cellular sites. These types of small cells differ in terms of the technology they operate on and the number of users they support, among other variables. But there are also a

Small cells	Cell Radius	Power(Watts)	AppNo of Users
Outdoor DAS	1mile	20	3,000 per sector
Indoor DAS	Up to 200 feet per antenna	2	2,500-3,000 per sector
Micro cell	1 mile	10	1,800 per baseband unit
Metro cell	500-1000feet	5	200
Pico cell	750 feet	1	32-160
Wi-Fi	50-60 feet	0.1	Up to 200 per access point
Femto cell	50-60 feet	0.1	4-80

Table 3.1: Key characteristics of various types of small cells.

number of similarities, which is why they get lumped together as small cells. Each of them operates at lower power and supports a smaller number of users than a typical, large-scale cell site.

Small cells are fundamentally about adding capacity by moving traffic off the macro network. They are all about network densification. In this sense, a distributed antenna system (DAS) can also be considered a small cell. A DAS adds capacity by offloading traffic and also operates at lower power while supporting a concentrated population of users. In fact, a DAS can be referred to as the original small cell. The table summarizes key characteristics about the various types of small cells.

	LICENSED SMALL CELLS	
	Femto	Pico
Indoor/outdoor	Indoor	Indoor/outdoor
Number of users	4 to 80	32 to 160
Maximum output power	20 to 100mW	250mW
Maximum cell radius	10 to 50m	200m
Bandwidth	10MHz	20MHz
Technology	3G/4G/Wi-Fi	3G/4G/Wi-Fi
MIMO	2x2	2x2
Backhaul	DSL,cable,fiber	Microwave.mm

Table 3.2: power source and abackhaul connection to the cellular network..

There are several different sizes and versions of small cells. They vary in the number of users they can handle, their power, and their range. In virtually all cases, they include the essential 3G technologies of the carrier, LTE and Wi-Fi. They also have a power source and a backhaul connection to the cellular network (see the table 3.2)

The smallest is the femtocell, which is a single-box base station used by the consumer to improve local cellular service. Femto cells have been around for years, and millions have been installed by most of the larger carriers. Backhaul is by way of the customer's high-speed Internet connection via a cable TV or DSL telecom provider. There are also enterprise femto that handle more users and provide a significant boost in indoor accessibility. There are progressively larger small cells such as the Pico cell, microcell, and metro cell, each with increasing capacity, power, and range. Virtually all handle legacy 3G, LTE, and Wi-Fi. Many future small cells will also feature LTE-Advanced.

3.2 Cells

The cellular network uses a number of low-power transmitters called base stations (BSs) and each BS covers a unit area called a "cell". A cellular network is a radio network made up of a number of radio cells (or just cells) each served by at least one fixed-location transceiver known as a cell site or base station. These cells cover different land areas to provide radio coverage over a wider area than the area of one cell, so that a variable number of portable transceivers can be used in any one cell and moved through more than one cell during transmission. Cell radius can vary from tens of meters in buildings and hundreds of meters in cities, up to tens of kilometers in countryside.

The shape of cells are never perfect circles or hexagons (as shown in figure 3.1), but depends on the environment (buildings, mountains, valleys etc.), on weather conditions, and sometimes even on system load. This typical system approach is being used by mobile telecommunication system, where a mobile station within the cell around a base station communicates with this base station and vice versa. In the rapidly increasing demand of cellular networks, cells are split into small size cells and are overlapping each other [24],[25]. Than has same advantage and disadvantage which are mainly; User capacity increases ,Number of handoffs per call increases and Complexity in locating the subscriber increases. There is lower

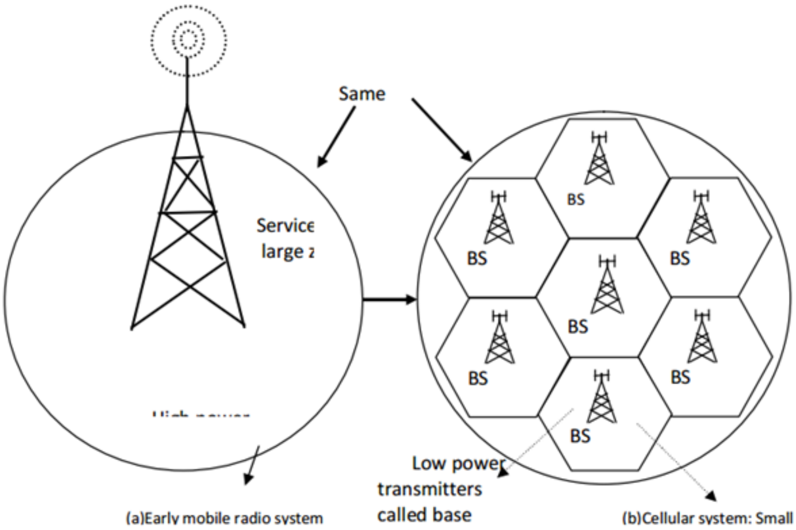

Figure 3.1: Early Mobile Radio System and Cellular System

power consumption in mobile terminal, so it gives longer talk time and safer operation. Thus, by reducing size of cells, user capacity of cellular networks can be increased. With initial development of macrocell, new micro, Pico and femto networks have been developed. Currently, cellular networks consist of four tiers (layers) of cells i.e. (i) Macro cell (ii) microcell, (iii) Pico cell (iv) femtocell

3.3 Hierarchical Cellular Network

Hierarchical cellular network consist of four tiers (layers) of cells (i) macrocell (ii) microcell, (iii) Pico cell (iv) femtocell. In this network larger cells are overlaid by the smaller cell and subscribers are divided into different types of classes (classified by speed) (i) low speed mobile terminal (LSMT) (ii) High speed mobile terminal (HSMT). Subscribers are assigned to the different cells (layer or tier). Generally, Macrocells are deployed in rural areas and have good coverage for vast users whereas, microcells concept has been developed to satisfy the high traffic demand in the urban regions and smaller cell lead to increase the capacity in small areas. The most common form of small cells is Pico cells and femtocells. Femtocells were initially designed for residential and small business, with short range and limited number of channels. For Pico and micro-cellular networks, the name 'personal' communication is often used. Most macro-cellular telephone networks are designed to be carried in Vans and also too bulky and power consuming is not conveniently portable. With micro and Pico cellular networks, low transmit powers less than 20 mW, can be used. Pico and femto cellular networks are mostly used for residential areas. The cell radius of these four cellular networks (Fig. 3.2) is: Macro-cellular, with cell radius 1- 30km,Micro-cellular, with cell radius 200 - 2000m ,Pico-cellular, with cell radius 4 - 200m and Femto-cellular, with cell radius 1-50m

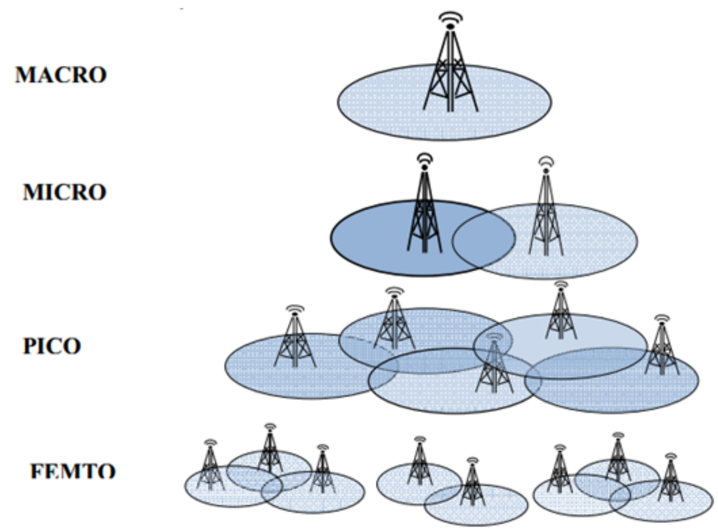

FIGURE 3.2: Difference Cells .

3.3.1 Macrocell

A macrocell is a cell in a mobile phone network, that provides radio coverage, is served by a high power cellular base station (tower). Generally, macrocells provide larger coverage than microcell. The antenna for macrocells are mounted on ground based masts, rooftops and other existing structures, at a height that provides a clear over view of the surrounding buildings and land. Macrocell base stations have power outputs of typically tens of watts. In rural areas, high base stations are installed to cover longer distance and macrocell is used to describe the widest range of cell sizes.

These are found in rural areas or along highways. The power of macrocell base stations is high, in order to maximize the covered distances. This kind of environment, due to the low number of customers and the high price of powerful base stations, the operators have always been trying to ensure minimal coverage so that voice calls can be performed outside. The deployment of such a network is very often done by combining wireless network planning tools and real measurements. The disadvantage of a macrocell network is that the network is deployed by only taking into account the outdoor coverage that is why in many rural areas it is still necessary to go outside of the building to be able to make a call. In order to optimize indoor coverage, the option for operators is to add more macrocell. However, such equipment is expensive, not only in terms of buying cost, but also in terms of maintenance."

3.3.2 Microcell

By cell splitting, the big cell is subdivided into smaller cells called microcells. Typically the range of a microcell is less than two kilometers. The microcells are cells with small radius and employed in highly populated areas such as city buildings and streets to meet high system capacity. These systems are typically used to provide low cost mobile phone systems in high density environments such as large cities. The microcell in mobile phone network is served by low power cellular base stations. A microcell is usually larger than a Pico cell, though the distinction is not always clear. A microcell uses power control to limit the radius of its coverage area. Microcells increase capacity of the channel, but radio resource management becomes more difficult. As compared to macrocell, microcells are more sensitive due to short term variations such as traffic and interference with medium or long term alterations (new buildings).

The main disadvantage of a micro cell structure is that the number of handoffs per cell increases, however, at the same time, the time available to make a handoff, decreases. Due to the increase in the microcell boundary crossing and expected high traffic loads, a higher degree of decentralization of the handoff process becomes necessary.

3.3.3 Pico cells

“One of the major challenges for the next generation wireless communication system is to improve the indoor coverage and provide high data rate services to the users in a cost effective manner as well as to increase the network capacity. Moreover, over the next few years, billions of devices will be connected to the internet and cloud based applications using 3G and 4G and LTE mobile wireless networks creating tremendous demand for mobile wireless capacity and ubiquities coverage”
“A Pico cell is a small cellular base-station. Typically, covering a small area such as in buildings (shopping malls, train stations, offices, airports etc.) or more recently in aircrafts.

In cellular networks, Pico cells are typically used to extend network coverage to indoor areas, where outdoor signals do not reach as well as to add network capacity in areas with very dense mobile phone uses, such as train stations. Pico cells provide good coverage and capacity in difficult areas as compared to expensive and more traditional macrocell approach. Pico cells are even smaller than microcell. It is typically used for indoor networks. Because of building’s walls have weaken signal strength, Pico cells can be particularly helpful for overcoming such problems.

Pico cells are available for most cellular technologies including GSM, CDMA, UMTS and LTE from manufacturers including IP Access [3]. Typically the range of Pico cell is 200 meters or less. But for this thesis only LTE cellular technologies are available in Pico cells. In Wi-Fi, the “user connects to a device called an Access Point (AP), which integrates an antenna to make the link between the user and the Internet. Basically Pico cell is a small base station very similar to an access point. It is usually small (Likely A4 size paper, and a few centimeters thick), and integrates an antenna that radiates a low power signal. Indeed, a Pico cell is a simplified base station, with low power and lower capacity than microcell or macrocell base stations. It connects to the Base Station Controller (BSC) or the operator.

As with standard base stations, the BSC manages the transmission of data between the Pico cell and the network, and performs the hand-over between the cells and the allocation of the resources to the different users. Some of the advantages of the Pico cell" are: They are cheaper than standard base stations and the cost of installation is also less. The coverage area of the cells is small compared to outdoor base stations; because (i) radiated power is low and (ii) number of reflections and diffractions due to the walls and other obstacles inside the building. Hence, coverage of network inside the building requires use of several Pico cells compared to outdoor cells Allows the operator to have more cells and thus increases the capacity of the network inside the building. That is why Pico cells are installed indoors that have a high density of users. Operator can have more capacity in the outdoor network by installing a Pico cell inside a building as the outdoor cells that are used to cover the building become available just to outdoor users. In many situations, it also gives an opportunity to the operator to reduce the radiated power of the outdoor cells used to cover the building. That is why Pico cells not only increase the capacity inside the building but also increase the outdoor capacity, and reduce the outdoor interference.

Pico cells, being the small cells can also be used in scenarios where localization is important. Method of using outdoor cells and triangulation for indoor localization is not accurate enough due to the reflections from the obstacles. However, with small cells it can be easily ascertained in which building the user is in, but by deploying many Pico cells a more accurate position of the user is ascertained. Pico cells have lower transmit power than macro BSs, they have omnidirectional antennas unlike macro BSs which are sectored. The transmit power ranges from 250mW to 2W. They are generally used for indoor purposes around hot-spots like offices, railway stations etc. Pico cells are connected over X2 interface [26].

3.3.4 Femtocells

Femto cells are also known as HeNBs are deployment for small rooms and home requirements generally for a very small range coverage less than 50m. They have omnidirectional antennas, transmit power is around 100mW. They could be plugged in using a DSL line or modem cable [26].

Femtocell base stations (FBS) are proposed in order to improve indoor coverage and capacity. The FBS is a small cellular base stations connected through broadband. Different types of access control schemes have been presented: open access, closed access (for specific users or user groups), and hybrid access. In this paper we will address business aspects for deployment where the type of business model depends on the type of market. Business cases and white papers in Femto forum have a large focus on the consumer segment, families and voice services in homes [27],[28]. FBS is seen as a product that together with price plans is expected to increase customer loyalty and decrease churn. For the business segment another opportunity is to use femtocells for "offloading" of data traffic from the macro layer in cellular networks.

This aspect of femtocells has been increasingly important with the rapid growth of mobile broadband (MBB) services. The increasing use of MBB in combination with flat fee subscriptions has resulted in a decoupling of traffic from operator revenues. The offloading of data traffic from the macrocell layer to femtocells offers a large potential to reduce the need for investments in "more costly" macrocell networks. For all business segments the main added value of femtocells is the improved indoor coverage. However, in regions where the coverage from outdoor to indoor generally is good, bad indoor coverage can result in a switch to another operator that offers better coverage.

In order to satisfy the customer needs operators provide specific technical solutions where the radio signals are distributed indoors, e.g. distributed antenna systems (DAS) . In this market for indoor mobile voice solutions different types of cooperation are very common. DAS are often used for multi-operator networks, i.e. cooperation between operators. Operators also cooperate with business customers and with real estate owners. For Internet access companies provide fixed or wireless company networks for private access. Public WiFi3 access is offered by hot spot operators where "any" user can access the network if you have an agreement with the hot spot operator. The overall problem area to be discussed in this paper is how femtocells can fit into this picture with i) multi-operator networks for voice, ii) private "closed" data networks and iii)"open" public networks for wireless Internet access? Proposed femtocell solutions are single-operator networks which would imply deployment of multiple femtocell networks in offices and public places.

The economic feasibility and the practical aspects of deployment and operation of this "non-shared" approach can be discussed. Sharing of base station sites and spectrum is already in use for wide area 3G/UMTS systems and for indoor mobile voice (2G/GSM) so sharing approaches would be feasible also for femtocell networks. Base station sharing has further been agreed for 4G/LTE networks under implementation. It is likely that the role-out of Long Term Evolution (LTE) networks will include both outdoor macrocells and indoor femtocells from the early stage of network deployment. Femtocells are also very promising for enterprise applications.

A femtocell is a small cellular base station designed for use in residential or small Business environments [2]. It is connected to the service provider's network such as broadband (DSL or cable) and typically supports 2-4 active mobile phones in a residential areas, and 8-80 active mobile phones. In the indoor areas, where the service coverage is limited, a femtocell can be used to extend service coverage. It also decreases backhaul costs, since it routes mobile phone traffic through the IP network. A femtocell is sometime referred to as a "home base station" "access point base station", and "personal 2G-3G base station." A femtocell is a small device that is used to improve wireless coverage over a small area, mostly indoor. It is a small cellular base station, also called a wireless access point that connects to a broadband internet connection and broadcasts and mobile handsets can handle phone calls through the femtocell; via the broadband internet connection. Femtocell attracts the mobile operators by improving both coverage and capacity indoors. These can reduce both capital expenditure and operating expense. There may also be an opportunity for new services. Consumers benefit from improved coverage and potentially better voice quality and battery life. The 3 GPP refers to 3G femtocells as Home Node BS (HNBs).

In brief femtocells are essentially small footprint, low power 3G wireless radio systems that plug into a residential or business broadband connection to provide a mobile signal directly to that location (indoor coverage for residential/enterprise locations). Mobile phone subscribers can use their existing mobile handsets or broadband air cards to access voice, data, and video needs for a small number of users. A femtocell can typically service a residential environment with a range of up to 5,000 feet. The recent development of femtocells provides an opportunity to operators to address the poor indoor coverage problem.

With femtocells, all the communications go to the operator's network through the Internet, and there is no need for BSC/MSC infrastructure. Typically, femtocells cover a smaller area and have fewer users and they have to be cheap. There are output power and capacity between 10 and 20 dBm, between four to six users. Within femtocell networks, outdoor users connected to the macrocells. If they have handoff then they are connected to their femtocell. This ensures a smooth communication for the users and a maximal coverage is obtained inside the home. The main advantage for the femtocells is expected. Femtocell is very important for the following reasons: It can provide indoor coverage for places where macrocells cannot reach. A femtocell allow mobile operators to deliver data services at a very low cost and providing faster data speeds and better user experience inside the home. Femtocell represents a more cost-effective solution than do other indoor solution such as Distributed Antenna System (DAS). It can offload traffic from the macrocell layer and improve macrocell capacity.

Femtocell provides an ideal solution for FMC (Fixed Mobile Convergence). Femtocell plays an important role in mobile broadband and ubiquitous communications. Femtocells can provide significant power saving to user equipment's (UE). The path loss to indoor femtocell access point (FAP) is much smaller than that of outdoor macrocell base station and so it is the required transmitting power from UE to the FAP. Higher mobile data capacity; which is important if the user makes

Specifications	Femto cell	Pico cell
Transmit power	20 dBm	30dBm
Coverage distance	Less than 30 meters	Less than 100 meters
Backhaul connectivity	Broad Band	X2 interface
Accessed Mode	Closed subscribed Group	Open to all user
Deployment location	Indoor	Indoor as well as out door
Installation	By the user	By the operator
Cost	Very cheap	Cheap

Table 3.3: the difference between femto cell and pico cell.

use of mobile data on their mobile phone (may not be relevant to a large number of subscribers who instead use Wi-Fi where femtocell is located). Femtocells will improve service quality, hence it will increase customers loyalty and can reduce the operators cost. Femtocells are low cost solution to increasing indoor coverage and improving service quality as well as number of users [29],[30],[31].

Comparison of Pico cell and Femtocell

Femtocell capacity is generally defined as somewhere between 4 and 80 users, depending on the applications, whereas a Pico cell is generally thought to support 32 to 160 users or more. Femtocells are almost always equipped with automatic self-configuration capabilities whereas a Pico cell could include automatic or manual Configuration capabilities, or even a combination of both.

Femtocell is installed by customer whereas Pico cell is normally installed by operators. Pico cells tend to have a longer range than femtocells, which are designed to cover a user's home or small office or office floor or street corner. Femtocells are self-installed by the user in their home or office, primarily for their own benefit whereas Pico cells are normally installed and maintained directly by the network operator, who would pay for site rental, power and fixed network connections back their switching center [32].

Compared with Pico cells and other indoor technologies femtocells are low cost solution to increasing indoor coverage and improving service quality as well as number of users.

3.4 Indoor Propagation Models

Motivation for Indoor Propagation Models: Predicting the propagation characteristics between two antennas inside a building is important especially for the design of cordless telephones, wireless local area networks (WLAN), and in some cases, indoor cellular base stations.

The indoor propagation channel differs considerably from the outdoor one. The distance between transmitter and receiver is shorter due to high attenuation caused by internal walls and furniture and because of the typically lower transmitter power. The short distance implies a shorter delay of echoes and consequently lower delay spread.

The temporal variations of the channel are slower compared to mobile antennas moving in a car. As is the case in outdoor systems, there are several important propagation parameters to be predicted. The path loss and the statistical characteristics of the received signal envelope are most important for coverage planning applications. The wide-band and time variation characteristics are essential for evaluation of the system performance.

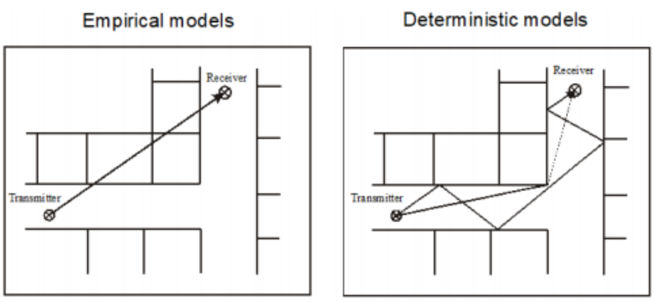

Figure 3.3: Difference approaches to the modeling of indoor propagation

The considered propagation models can be categorized into three groups [33]:

1. Empirical narrow-band models

2. Empirical wide-band models
3. Deterministic models

Empirical narrow-band models are expressed in the form of simple mathematical equations that give the path loss as output. The equations are obtained by fitting the model to measurement results.

The empirical wide-band models (dominant paths) also allow the prediction of the wide-band characteristics of the channel (for example, delay spread).

Deterministic models are calculation methods that physically simulate the propagation of radio waves. These models yield both narrow-band and wideband information of the mobile radio channel inside buildings. All of the presented models are based on or calibrated with propagation measurements.

These measurements have mostly been carried out at 1800 MHz which is most appropriate considering the common indoor systems [33],[34]. The usage of the models at other frequency bands is possible when the material parameters of the propagation environment are known.

Required Database:Categorize buildings into different elements and specify their material parameters for accurate indoor propagation modeling. The basis for any propagation model is a database which describes the propagation environment. For indoor propagation modeling, each building element is categorized into classes (for example, wall, floor, and door) and specified by its coordinates and finally its material properties (thickness, permittivity, and conductivity.

3.4.1 Modified Free Space Model (MF)

The modified-free-space model analyzes the building concerning distances between walls and penetration losses of the walls, but the individual positions of the walls and their material properties are not considered. This model computes the path loss similar to the free space loss with an adjustable exponent and offset. Herewith it assumes that the excess path loss (in dB) is linearly dependent on the distance with a specific attenuation coefficient n:

$$l_{MF} = n(20log(4 * pi * d)/lampda) + l_c[33] \tag{3.1}$$

The modified-free-space model does not consider the walls of the building, thus no database is required. With constant values for n and l˙c the prediction leads to field strength values decreasing in concentric circles around the transmitter. According to this the prediction results are fairly inaccurate and only suited for a rough estimation. . To calibrate this model with measurement data the exponent

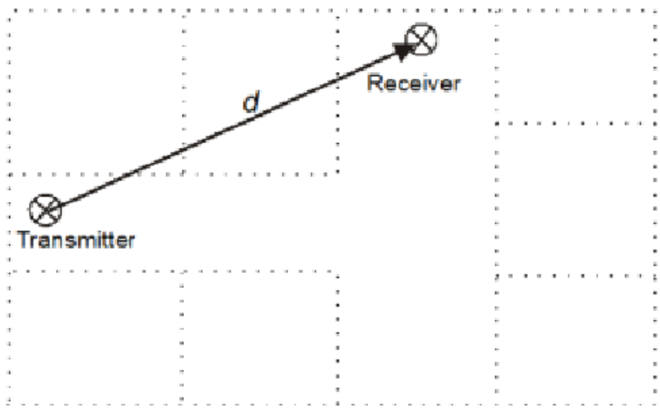

FIGURE 3.4: principle of the modified free space model .

and the offset to be used for this model can be specified by using the win-prop software tool Settings button. For line-of-sight to the transmitter, the values for n are in the range between 1.0 and 1.4, in non-line-of-sight scenarios values up to 2.0 are possible.

3.4.2 Motley-Keenan Model (MK)

The modified-free-space model analyzes the distances of the building between walls and penetration losses of the walls. The model according to Motley and Keenan computes the path loss based on the direct ray between transmitter and receiver.

In contrary to the modified free space model this model considers the exact locations of the walls, floors, and ceilings. Additional factors for absorption of the direct ray path by walls are considered.

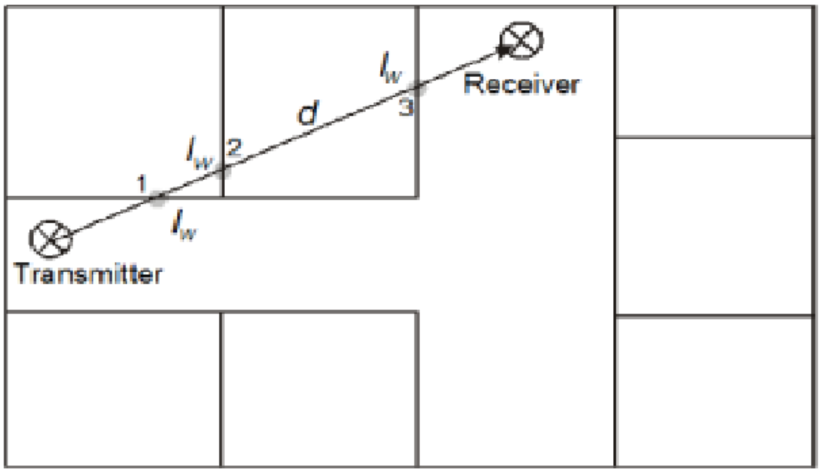

FIGURE 3.5: Principle of the Motley -Keenan model .

$$l_{MK} = l_{FS} + l_c + k_w l_w [33] \quad (3.2)$$

As shown in Figure 3.5 the parameter kw describes the number of walls intersected by the direct path between transmitter and receiver. A uniform transmission (penetration) loss l˙w for all walls is used for the computation, that is the material properties of the individual walls are not considered. This uniform transmission loss can be specified by using the Settings button.

3.4.3 COST-Multi-Wall Model (MW)

The multi-wall model gives the path loss as the free space loss including losses introduced by the walls and floors in the direct path between transmitter and receiver. The multi-wall model gives the path loss as the free space loss including losses introduced by the walls and floors in the direct path between transmitter and receiver (see Figure 3.6). It has been observed that the total floor loss is a function of the number of penetrated floors. This characteristic is taken into account by introducing an additional empirical correction factor. The individual penetration

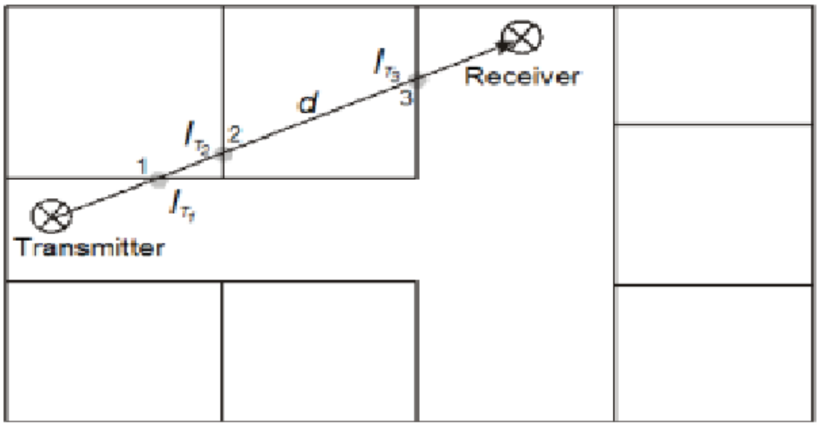

FIGURE 3.6: Principle of the multi-wall model.

losses for the walls (depending on their material parameters) are considered for the prediction of the path loss. Therefore the multi-wall model can be expressed as follows.

$$l_{MW} = l_{FS} + l_c + Sum_{i=1}^{N} k_{wi} l_{wi} + k_f l_f [33] \quad (3.3)$$

Where,

- l˙FS =free space loss between transmiter and receiver
- l˙c = constant loss
- k˙wi = number of penetrated wall of type i
- k˙f = number of penetrated floors
- l˙wi =loss of wall type i
- l˙f =loss between adjacent floors
- N=number of different wall types

It is important to note that the loss factors in the formula are not physical wall losses but model coefficients which are optimized with the measured path loss data. Consequently, the loss factors implicitly include the effect of furniture. This model has a low dependency on the database accuracy and because of this simple approach a very short computation time. However, wave guiding effects are not considered with this model leading to a moderate accuracy level. No preprocessing of the building data is needed for the computation of the prediction, and no settings have to be changed for Cost-multi wall prediction model.

3.4.4 I

TU (International Telecommunication Union) indoor propagation model
Model estimates the pathloss of radio propagation in the indoor environments. This model is applicable to frequency from 0.9 up to 5.2 GHz and to buildings with 1 to 3 floors. According to ITU indoor propagation model, the indoor propagation pathloss is:

$$L_{indoor} = 20logf + Nlogd + P_{f(n)} - 28 \quad (3.4)$$

in which,
f is the transmission frequency [MHz];
d is the transmission distance [m];
N is the distance power loss coefficient;
P˙f(n) is the floor loss penetration factor;
n is the number of floors via transmission

Chapter 4

Indoor Radio Network Planning: Coverage and Capacity Planning of Small Cells for Buildings Process

4.1 Pico cell and femto cell Radio Network Planning

In this thesis, indoor propagation model is applied in Pico and femto cell sites placement algorithm which will be addressed in chapter 5. It is just used for rough estimation of the pathloss from the newly added femto cell site. After femto cell placement is done, the pathloss will be calculated in win prop. Since only rough estimation is needed, the floor loss penetration factor Pf (n) is ignored here. And the distance power loss coefficient N is chosen to be 28 for ITU . Taking into account of the exterior wall loss L˙wall=12 since the Pico sites will be placed outdoor, the total pathloss estimation can be expressed as:

$$L = L_{indoor} + L_{wall} = 20logf + 28logd - 16 \quad (4.1)$$

$$L - 20logf + 16 = 28logd \tag{4.2}$$

$$((L - 20logf + 16))/28 = logd \tag{4.3}$$

$$d = 10^{((L-20logf+16)/28)} \tag{4.4}$$

$$L = 20log10(1800MHz) + 28logd - 16 = 185.1dB + 28logd - 12dB \tag{4.5}$$

$$L = 173.1dB + 28logd \tag{4.6}$$

$$d = 10^{((L-173.1dB)/28)} \tag{4.7}$$

Cost-multi Wall is used to estimate the path loss of this thesis.

$$Formultiwall, L_{cost-multiwall} = L_{fs} + L_c + sum_{i=1}^{N} k_{wi} L_{wi} + k_f L_f \tag{4.8}$$

$$L = 20log10(4*pi*d/6)+18.2dB = 6.4dB+20log10(d)+18.2dB = 24.6dB+20log10(d) \tag{4.9}$$

$$L - 24.6dB = 20log10(d) \tag{4.10}$$

$$(L - 24.6dB)/20 = log10(d) \tag{4.11}$$

$$10^{(((L-24.6dB))/20)} = d, atf = 1800MHz \tag{4.12}$$

The distance can also be estimated by adding exterior wall loss =12 from the following

$$L = 20log10(4*pi*d/6)+18.2dB+10l0g10(12) = 6.4dB+18.2dB+10.79dB+20log10(d) \tag{4.13}$$

$$L = 35.39dB + 20log10(d) \tag{4.14}$$

$$L - 35.39dB = 20log10(d) \tag{4.15}$$

$$(L - 35.39)/20 = logd \tag{4.16}$$

$$d = 10^{((L-35.39)/20)} \tag{4.17}$$

$$L_{cost-multiwall} = 20log10(4 * pi * d) + 18.2dB \tag{4.18}$$

$$L_{cost-multiwall} = 20log10(4{*}pi{*}d/6){+}18.2dB = 20log10(0.67{*}d){+}18.2dB = 47.3dB, \quad (4.19)$$

$$20log10(0.67 * d) + 18.2dB = 20log10(1800MHz) + 28logd - 16 \quad (4.20)$$

$$20log10(0.67 * d) + 18.2dB = 185.1dB + 28logd - 16 \quad (4.21)$$

$$20log10d - 28logd = 185.1dB - 14.7dB - 12dB = -8logd = 158.36dB \quad (4.22)$$

distance (d)=10.48m

The distance in this system is 10.48 meters.by substitute the distance in the following equation the total loss estimation with ITU and L˙cost-multi wall are as follows:

$$L = L_{indoor} = 20logf + 28logd - 28 = 185.1dB + 28.57dB - 14.47dB = 199.2dB \quad (4.23)$$

$$L_{total} = 199.2dB, atd = 10.48meter \quad (4.24)$$

$$L_{cost-multiwall} = 20{*}log10(0.67{*}d){+}18.2dB = 26.8dB{+}18.2dB = 35.12dB \quad (4.25)$$

To estimate the total path loss in the femto sites the exterior wall loss will not be considered. Since the femto sites had been inside, it can be expressed as:

$$L = L_{indoor} = 20logf + 28logd - 28 \quad (4.26)$$

$$20log10(0.67 * d) + 18.2dB = 20logf + 28logd - 28 \quad (4.27)$$

$$20log10(0.67 * d) - 28logd = 20logf - 28 - 18.2dB \quad (4.28)$$

$$20log10(0.67 * d) - 28logd = 20log10(1800MHz) - 18.2dB \quad (4.29)$$

$$20log10(0.67) + 20logd - 28logd = 185.1dB - 14.7dB - 18.2dB = 152.2dB \quad (4.30)$$

$$-8logd = 152.2dB \quad (4.31)$$

$$d = 12.5meter \quad (4.32)$$

The femto cell distance would be 12.5meters and above in this thesis. Hence Femto cell estimated total loss maximum and minimum value are with ITU and

L˙cost-multi wall listed below:

$$L = L_{indoor} = 20logf + 28logd - 28 = 185.1dB + 30.71dB - 14.47dB = 201.33dB, atd = 12.5meter \tag{4.33}$$

$$L_{cost-multiwall} = 20log10(0.67*d) + 18.2dB = 18.46dB + 18.2dB = 36.66dB, atd = 12.5meter \tag{4.34}$$

$$L_{cost-multiwall} = 14.46dB, atd = 1meterTheonlydifferencebetweennd = 1meter, 12.5meterand1 \tag{4.35}$$

4.2 Pico Cell and femto cell Coverage planning

Chip and information rates: the femtocell and Pico cell node gives an average downlink throughput of 24 Mbps chip rate with 24.436 kbps Bit rate and uplink throughput of 14 Mbps chip rate with Bit rate 14.090 kbps. The processing gain is defined by the equation.

$$Processinggain = 10 * log(ChipRate/BitRate) \tag{4.36}$$

$$downlinkprocessinggain = (24 * 10^6)/(24.436 * 10^3) = 982.157 \tag{4.37}$$

$$downlinkprocessinggain(dB) = 10 * log982.157 = 29.92dB \tag{4.38}$$

$$Uplinkprocessinggain = (14 * 10^6)/(14.090 * 10^3) = 993.61 \tag{4.39}$$

$$uplinkprocessinggain(dB) = 10 * log993.61 = 29.97dB \tag{4.40}$$

Thermal noise spectral density: the thermal noise density is computed from the equation: Spectral density of thermal noise is kT. It is -174dBm/Hz in room temperature (300K).

$$N = KT = 1.38 * 10^{-23}) * 290,000 = 4.002 * 10^{-23}) \tag{4.41}$$

$$NdB = 10log10(4.002 * 10^{-23}) = -174dBm/Hz \tag{4.42}$$

$$Bandwidthperchiprate = 24Mchip/s = 24 * 10^6)chip/s \tag{4.43}$$

$$BdBperchipratedB = 10log10(24 * 10^6) = 73.80dB \tag{4.44}$$

Thermal noise power: the thermal noise density is computed from the equation: Thermal Noise Power =

$$Boltzmann'sConstant * Temperature * Bandwidth \tag{4.45}$$

$$N_i = KTB \tag{4.46}$$

Where is Boltzmann constant, which equals 1.38*10ˆ-23 J/K,T is absolute temperature (To =290K), and B is system bandwidth.

$$N_i chiprate/sDownlink = 1.38 * 10^{-23} * 290000 * 24x10^6 = 9.6048 * 10^{-11} \tag{4.47}$$

$$N_i(dB) = 10log10(KToB) \tag{4.48}$$

$$= NdB + BdB \tag{4.49}$$

$$= -100.2dBm \tag{4.50}$$

$$BandwidthperchiprateinUplink = 14Mchip/s = 14 * 10^6 chip/s \tag{4.51}$$

$$Bandwidthperchiprate(dB) = 10 * log(14 * 10^6) = 71.46dB \tag{4.52}$$

$$N_i chiprate/sUplink = 1.38 * 10^{-23}) * 290000 * 14 * 10^6 = 5.6028 * 10^{-11} \tag{4.53}$$

$$N_i(dB) = 10 * log(KToB) \tag{4.54}$$

$$= NdB + BdB \tag{4.55}$$

$$-174dBm/Hz + 71.46dB/s = -102.54dBm \tag{4.56}$$

Reference Noise Level for Pico cell

The noise power density is frequency-independent: the noise power remains the same no matter what the radio frequency. The noise power is equally distributed throughout the spectrum and is related to the bandwidth of the RF channel The

Pico cell radio channel is 20 MHz .This makes the thermal noise floor for Pico cell

$$KTBforPicocell(20MHZ) = -(174dBm)/HZ + 10log10(20*10^6 Hz) = -101dBm \tag{4.57}$$

The Femto cell radio channel is 10 MHz .This make the thermal noise floor for Femto Cell

$$KTBforFemtocell(10MHz) = -174dBm/Hz + 10log10(10*10^6 Hz) = -104dBm \tag{4.58}$$

Noise Factor: The noise factor (F) is defined as the input signal-to-noise ratio (S/N or SNR) divided by the output signal-to-noise ratio. In other words the noise factor is the amount of noise introduced by the amplifier itself, on top of the input noise. For a passive system such as a cable, the SNR would also be degraded, by attenuating the signal nearer to the thermal noise floor would equally degrade the SNR. The noise factor is a linear value:

$$Noisefactor(F) = (SNRinput)/(SNRoutput) \tag{4.59}$$

$$Picocellnoisefactor = -85dBm - (-101dBm) = 16dBm, (39.81) \tag{4.60}$$

$$Femtocellnoisefactor = -85dBm - (-104dBm) = 19dBm, (79.43) \tag{4.61}$$

Noise Figure: The noise figure (NF) is noise factor described in dB, and is the most important figure to note on the uplink of any DAS or amplifier system. The NF will affect the DAS sensitivity on the uplink, and will determine the performance of the uplink. This will be the limiting factor for the highest possible data rate the radio link can carry, no matter whether it is 2G, 3G and 4G or any other service. The lower the NF, the better the performance.

$$Noisefigure(NF) = 10log(F) \tag{4.62}$$

$$Picocellnoisefigure = 10log(39.81) = 16dB \tag{4.63}$$

$$Femtocellnoisefigure = 10log(79.43) = 19dB \tag{4.64}$$

Noise Floor: The noise floor is the noise power at a given noise figure at a given bandwidth; we can calculate the noise power or noise level for a receiver, amplifier or any other active component.

$$Noisepower(noisefloor) = KTB + NF + gainofthedevice \tag{4.65}$$

$$Picocellnoisepower(noisefloor) = -101dBm + 16dB + 0 = -85dBm \tag{4.66}$$

$$Femtocellnoisepower(noisefloor) = -104dBm + 19dB + 0 = -85dBm \tag{4.67}$$

The receiver sensitivity: Knowing the NF and bandwidth of the receiver in the BTS, we can calculate the receiver sensitivity. However, first we need to calculate the noise floor of the receiver. To calculate the minimum required level the receiver will be able to detect to produce the quality needed for voice (without adding any fading margins):

$$Receiversensitivity = receivernoisefloor + serviceSNRrequirement \tag{4.68}$$

$$ReceiversensitivityofPicocell = -85dBm + 16dBm = -69dBm \tag{4.69}$$

$$Receiversensitivityoffemtocell = -85dBm + 19dBm = -66dBm \tag{4.70}$$

Receiver thermal sensitivity - The receiver thermal sensitivity is computed according to the equation:
Receiver thermal sensitivity=

$$effectivenoisepower + servicesSNRrequirement - Processinggain \tag{4.71}$$

$$ReceiverthermalsensitivityofPicocell = -85dBm + 16dBm - 29.92dB = -98.92dBm \tag{4.72}$$

$$Receiverthermalsensitivityoffemtocell = -85dBm + 19dBm - 29.92dB = -95.92dBm \tag{4.73}$$

Thus the lowest detectable signal for a Pico cell and femto cell will be negative 98.92 dBm and negative 95.92dBm respectively.

Therefore the receiver sensitivity for Pico cell and femto cell are negative 98.92

dBm and negative 95.92dBm respectively with excluding of any fading margins.

4.2.1 Pico cell and femto cell 4G Link Budget

Isolation:Isolation plays a key role in indoor signal analysis. Isolation is basically defined as the difference between two signal levels i.e. signals level outside to the signal level inside. One of the alternative ways to consider the isolation phenomena is that the dominance of the indoor network should be high as compared to the outdoor macro network when an indoor user is at the boundary of the building.
If isolation is good then unwanted interference may not arise that causes deterioration of the wanted signal level like other radio systems we need to maintain a good clean serving cell signal, with good Isolation to any other cells on same frequency. In 4G we have a frequency reuse of 1, all cells using same frequency. For well-isolated, high-capacity Cells in a DAS, it is recommended to be about 10-15 dB more dominant than other cells in Most of the coverage area. Obviously there will be 'transition' areas where we need to Have an overlap – make sure to plan these handover areas in places where there is limited.
Capacity load:Receiver blocking on 4G to avoid saturation of the receivers in 4G, it is highly recommended not to exceed –25 dBm reference symbol received power (RSRP).

4.2.2 Pico cell and femto cell 4G Design Levels

In 2G we designed for Rx-Level, and in 3G we designed for CPICH level; in 4G, RSRP is the reference and a design target level of negative 95 to negative 85 dBm seems to be standard among most Mobile operators, with negative 80 dBm in high-demand areas, and even negative 75 to negative 70 dBm RSRP in VIP Areas. Like any other RF system, the actual design target level will depend on the interference Level in the building, and we have to adjust the design level to overcome this interference.

Basement and low-interference areas: –100 to –95dBm RSRP [1].

Office and high-use environment, with limited interference: –90 dBm RSRP [1].

High rises, high-use critical areas with some interference: –85 dBm RSRP [1].

High-interference areas: even higher than –85 dBm RSRP design level [1].

We must keep in mind that the total composite power of the 4G base station must be shade By the sub-carriers in service. The number of sub-carriers relates to the RF channel bandwidth

4.2.2.1 Pico cell 4G Design Level

The RF channel bandwidth of Pico cell is 20 MHz Hence the 20 MHz bandwidth allows 100 Physical resource blocks (PRBs). Each PRB comprises 12 sub-carriers so there is a total of 100x12=1200 sub-carriers to share the composite power resource.

4.2.2.2 Femto cell 4G Design Level

The bandwidth of femto cell is 10MHz.Hence the 10MHz bandwidth allows 50 PRBs. Each PRB comprises 12 sub-carriers so there is a total of 50x12=600 sub-carriers to share the composite power resource.

4.2.3 Pico cell and femto cell RSRP, Reference Symbol Transmit Power

The RSRP is used to measure the RF level of the cell for mobility management. The RS is also Used to identify the individual MIMO paths. The RSRP is the linear-averaged RS signal level Over the six RS in each resource block (RB). In order to calculate the link budget, we first need To be able to calculate the transmitted power of the RS. The RS transmit power relates to the Bandwidth of the 4G channel (the number of sub-carriers).

4.2.3.1 Pico cell RSRP, Reference Symbol Transmit Power

A 20 MHz 4G channel and a composite power of the transmitter Of 30 dBm. We can see that a 20 MHz channel has 100 RBs. Each RB comprises 12 sub-carriers, giving a total of 100 x 12 =1200 sub-carriers.
Therefore each of the 1200 sub-carriers gets assigned 1/1200 of the total power. Hence it will be able to calculate the power assignment to each sub-carrier in relation to the total power:

$$Powerdroppersub{-}carrierof1200sub{-}carrier = 10log(1200) = 30.79dB \quad (4.74)$$

Now we can calculate the transmitted power (TxPWR) per sub-carrier:

$$TxPWRRSRP = totalpower–(powerdroppersub - carrier) \quad (4.75)$$

$$TxPWRRSRP = 30dBm - 30.79dB = -0.79dBm \quad (4.76)$$

$$TxPWRRSRPof4GPicocell = -0.79dBm \quad (4.77)$$

4.2.3.2 Femto cell RSRP, Reference Symbol Transmit Power

A 10 MHz 4G channel and a composite power of the transmitter Of 20 dBm. We can see that a 10 MHz channel has 50 RBs. Each RB comprises 12 sub carriers, giving a total of 50 x 12 = 600 sub-carriers.
Therefore each of the 600 sub-carriers gets assigned 1/600 of the total power. Hence it will be able to calculate the power assignment to each sub-carrier in relation to the total power:

$$Powerdroppersub-carrierof600sub-carrier = 10log(600) = 27.78dB \quad (4.78)$$

Now we can calculate the transmitted power (TxPWR) per sub-carrier

$$TxPWRRSRP = totalpower–(powerdroppersub-carrier) \quad (4.79)$$

$$TxPWRRSRP = 20dBm - 27.78dB = -7.78dBm \quad (4.80)$$

$$TxPWRRSRP4GFemtocell = -7.78dBm \quad (4.81)$$

4.2.4 Pico cell and femto cell RSSI Signal Power

The received signal strength indicator (RSSI) is the total composite received strength of a Radio channel, a 'raw' RF measurement over the full channel bandwidth. In case of pico cell and femto cell, the RSSI is the sum of the power of all active sub-carriers. Therefore the RSSI is dependent on the bandwidth of the carrier; the wider the bandwidth, the more sub-carriers will be transmitted. When designing the systems, we take as our reference the RSRP. We can calculate the Expected RSSI of the full channel when we know the RSRP level. This is very useful when Measuring signal strength and power levels in pico and femto systems.

4.2.4.1 Pico cell RSSI Signal Power

When designing Pico cell systems, we take as our reference the RSRP. We can calculate the Expected RSSI of the full Pico cell channel when we know the RSRP level. This is very useful when Measuring signal strength and power levels in Pico cell systems, if we do not have the equipment that can decode and measure the RSRP directly. Let's try to calculate the RSSI when we know the RSRP we are designing for, using the same approach as before and using the values of Pico cell, on a 20 MHz carrier. A 20 MHz pico carrier has 100 RBs, each with 12 sub-carriers, giving a total of 100 * 12 = 1200 sub carriers.

$$Thisisapoweroffsetof: 10 * log(1200) = 30.79dB. \tag{4.82}$$

This means that the RSRP is 30.79dB Lower than the RSSI. If we were designing for –85dBm RSRP then the expected RSSI would be 30.79dB higher:

$$RSSI = RSRP + offset \tag{4.83}$$

$$RSSI = -85dBm + 30.79dB = -54.21dBm(infull20MHz)bandwidth \tag{4.84}$$

4.2.4.2 Femto cell RSSI Signal Power

A 10 MHz femto carrier has 50 RBs, each with 12 sub-carriers, giving a total of 50 x 12 = 600 sub carriers.
This is a power offset of:

$$10 * log(600) = 27.78dB. \tag{4.85}$$

This means that the RSRP is 27.78dB Lower than the RSSI.

$$RSSI = RSRP + offset \tag{4.86}$$

$$RSSI = -85dBm + 27.78dB = -57.22dBm(infull10MHz)bandwidth \tag{4.87}$$

Typical Pico cell and femto cell Design Levels: Obviously, the exact RSRP design target level is dependent on the actual interference in the building, noise power from any active elements, and losses from passive elements. Typical design levels will often range from –87 dBm RSRP in low-interference areas up to more than –65 dBm for high-interference areas.

4.2.5 Pico cell and femto cell Coverage vs. Capacity

As we can see Pico cell and femto cell, there is a difference in the assigned RS transmit power, depending on the transmitted pico cell and femto cell channel bandwidth, according to the number of sub-carriers supported by the actual channel bandwidth. If we consider a DAS remote unit with a composite Power capability of 30 dBm and 20dBm respectively, we can calculate the transmitted RS power level .

According to the actual Pico cell and femto cell 4G channel bandwidth by compensating with the RS power offset to design more coverage-driven areas (sectors) in DAS for the low-capacity part of the system, and other cells in the same project could be more focused on capacity with a wider bandwidth, needing more DAS equipment to support the wider bandwidth, and hence higher power levels in the building.

4.2.6 Pico cell and femto cell 4G DL RS Link Budget

Let us make a brief RS DL simple link budget for a 20 MHz and 10 MHz carrier. We assume a base station with 30 dBm and 20 dBm for Pico cell and femto cell respectively of composite power output, feeding DAS with 0.46dB of loss; we are aiming for an RSRP level of –85 dBm:

Calculating the RS Pico cell transmit power from the base station

$$PicocellBasestationcompositepower = 30dBm \tag{4.88}$$

$$Referencesignalpowerdrop = 30.79dBm \tag{4.89}$$

Reference signal output power at Pico cell base station =

$$30dBm – 30.79dB = -0.79dBm \tag{4.90}$$

Calculating the RS transmit power from the DAS antenna

DAS loss = 0.46dB, omnidirectional antenna gain = 0 dBi

$$RSEiRP = BSRSpower – DASloss + DASantennagain \tag{4.91}$$

$$RSEiRP = -0.79dBm – 0.46dB + 0dB = -1.25EiRP \tag{4.92}$$

Calculating the MAPL: The MAPL is the difference between the transmitted powers and the desired receive power including fading margins and body losses. From the above we have:

$$RSEiRP = -1.25dBm \tag{4.93}$$

$$RStargetlevel = -85dBm \tag{4.94}$$

So without any margins,the maximum loss we can allow is

$$–1.25dBm – (–85dBm) = 83.75dB. \tag{4.95}$$

However, we also need to take into account a typical ‘body losses of 0.46dB and an additional 0.34 dB of multipath and log-normal fading, a total sum of 0.8 dB. MAPL including body loss and fading margins dB

$$= 83.75 - 0.8 = 82.95dB. \tag{4.96}$$

Calculating the RS Femto cell transmit power from the base station

$$Basestationcompositepower = 20dBm \tag{4.97}$$

$$Referencesignalpowerdrop = 27.78dBm \tag{4.98}$$

Reference signal output power at base station

$$= 20dBm – 27.78dB = -7.78dBm \tag{4.99}$$

Calculating the RS transmit power from the DAS antenna

DAS loss = 0.46 dB, Omni directional antenna gain = 0dBi

$$RSEiRP = BSRSpower–DASloss + Omniantennagain \tag{4.100}$$

$$RSEiRP = -7.78dBm–0.46dB + 0dB = -8.24dBmEiRP \tag{4.101}$$

Calculating the MAPL

$$RSEiRP = -8.24dBm \tag{4.102}$$

$$RStargetlevel = -85dBm \tag{4.103}$$

So with out any margins, the maximum loss we can allow is

$$–8.24dBm–(–85dBm) = 76.76dB. \tag{4.104}$$

MAPL including body loss and fading margins dB

$$= 76.76 - 0.8 = 75.96dB. \tag{4.105}$$

Maximum Allowed Path Loss (MAPL)
The Maximum Allowed Path Loss (MAPL) for each service and in every environment can be Computed for uplink and downlink. Uplink and downlink load factors are assumed based upon the traffic density expectation. The transmit EIRP and receiver sensitivities are calculated as are the net gains and losses of the radio Link. Finally the maximum allowed path loss is computed for both the uplink and downlink. The uplink is generally the limiting link in terms of radio bearer coverage. Nevertheless the downlink is checked to verify this assumption.

4.2.6.1 budget for femto cells

Like any other RF system, we will need to do a link budget when planning with femtocells. Often we will plan with a few selected types with the same output

Morphology	Units	IndoorFemto cell	Formula
Datachanneltype		PDSCH	
DuplexMode		FDD	
TX Power	dBm	20	a
Allocated RB		3	b
RB		50	c
Subcarrier		600	d=12xc
Subcarrier Power	dBi	-7.78	e=a-10log10d
TX Antenna Gain	dB	0	f
TX Cable loss	dB	0	g
TX Body Loss	dB	0.46	h
EIRP	dBm	-8.24	i=e+f-g-h
RX Antenna gain	dBi	0	j
RX Cable + connector loss	dB	4	k
RX Body Loss	dB	0	l
Noise Spectral Density	dBm/Hz	-174	m=kT
Bandwidth	dB Hz	70	n=10log10(10ˆ7)
Noise Power	dB/Hz	-104	o=kTB
Noise Figure	dB	19	p
SINR	dB	-7.78	q
Receiver Sensitivity	dBm	-92.78	r=o+p+q
Area Coverage Probability	%	95	
Edge Coverage Probability	%	90	
Slow Fading Standard Deviation	dB	6	
Slow Fading Margin	dB	0	s
Interference Margin	dB	0.46	t
Indoor Penetration Loss	dB	0	u
Sum of Margins	dB	0.46	v=s+t+u
MAPL	dB	81.08	w=i+j-k-l-r-v
Frequency Band	MHz	1800	
Propagation Model		Cost multi-wall	
Cell Radius	m	17	10ˆ((u-35.39)/20)

TABLE 4.1: Femto cell down link budget

power, noise figure and capacity, and will be able to generalize their coverage range in certain area types. Both femto cells and Pico cells are Uplink limited. Hence the link budget is only consider the downlink budget.

Determining the Number of BTS's (NodeB)

For this thesis work,we considered hexagonal,omni-directional or tri-sector cells in a single base station to provide precise coverage for the selected building. The coverage area of the hexagonal,Omni-directional or tri-sector base station is determined using the following formula [35],[36].

site coverage area ,

$$= A = 1.95d^2 \tag{4.106}$$

Where A is maximum area covered by a single base station and d is radius of single cell

For this thesis work,hexagonal, omni-directional or tri-sector cells in a single NodeB are considered to provide precise coverage for the selected 2,500mˆ2 (50x50m)femto cell coverage area. . The coverage area of one NodeB, of hexagonal, omni directional antenna and a tri-sector is determined by the above equation . And from femto cell link budget calculation cell radius is 17m. Therefore, the coverage area of one NodeB site will be 563.55mˆ2=(17x17m)x1.95. Hence, 17 meters of coverage in a typical residential building the coverage dimensioning perspective,

$$NumberofNodeBsites = Totalcoveragearea/oneNodeBsitearea \tag{4.107}$$

$$= 2,500 * 1.95m^2/563.55m^2 = 4875m^2/563.55 = 9NodeBsites \tag{4.108}$$

we need 9 NodeB sites to provide femto cell service throughout the entire 4875 mˆ2 area of femto cell indoor area.in case of G +3 Auto cad building design consists: Floor 1 take as site 1 consists:

$$3NodeBsites \tag{4.109}$$

Floor 2 take as site 2 consists:

$$3NodeBsites \tag{4.110}$$

Floor 3 take as site3 consists:

$$3 NodeBsites \tag{4.111}$$

As explained in the above site one to three sites consists of 17x17 m office for every NodeB sites with Omni directional antenna.

4.2.6.2 budget for Pico cells

Morphology	Units	Indoor pico cell	Formula
Datachanneltype		PDSCH	
DuplexMode		FDD	
TX Power	dBm	30	a
Allocated RB		3	b
RB		100	c
Subcarrier		1200	d=12xc
Subcarrier Power	dBi	-0.79	e=a-10log10d
TX Antenna Gain	dB	0	f
TX Cable loss	dB	0	g
TX Body Loss	dB	0.46	h
EIRP	dBm	-1.25	i=e+f-g-h
RX Antenna gain	dBi	0	j
RX Cable + connector loss	dB	4	k
RX Body Loss	dB	0	l
Noise Spectral Density	dBm/Hz	-174	m=kT
Bandwidth	dB Hz	73	n=10log10(2*10ˆ7)
Noise Power	dB/Hz	-101	o=kTB
Noise Figure	dB	16	p
SINR	dB	-0.79	q
Receiver Sensitivity	dBm	-85.79	r=o+p+q
Area Coverage Probability	%	95	
Edge Coverage Probability	%	90	
Slow Fading Standard Deviation	dB	6	
Slow Fading Margin	dB	0	s
Interference Margin	dB	0.46	t
Indoor Penetration Loss	dB	0.34	u
Sum of Margins	dB	0.8	v=s+t+u
MAPL	dB	79.74	w=i+j-k-l-r-v
Frequency Band	MHz	1800	
Propagation Model		Cost multi-wall	
Cell Radius	m	17.68	10ˆ((u-35.39)/20)

Table 4.2: pico cell down link budget

For this thesis work, hexagonal,Omnidirectional and tri-sector cells in a single NodeB are considered to provide precise coverage for the selected 40,000(200*200)pico cell coverage.The coverage area of oneNodeB, of a tri-sector is determined by equation (4.106). And from Pico cell link budget calculation cell radius is 17.68m. Therefore, the coverage area of one NodeB site will be 609.54 =(17.68*17.68)1.95. Hence, 17.68 meters of coverage in an open office environment the coverage dimensioning perspective, we need 127 NodeB sites to provide Pico cell service throughout the entire Pico cell indoor area. In Pico cell area the floors are similar with femto cell .but Pico cell have 17.68x17.68 m with including indoor and outdoor wall loss and it needs additional NodeB sites for every floors.

$$NumberofNodeBsites = Totalcoveragearea/oneNodeBsitearea \tag{4.112}$$

$$= 40,000 * 1.95m^2/609.54m^2 = 78,000m^2/609.54 = 127NodeBsites \tag{4.113}$$

4.3 Pico Cell and femto cell Capacity planning

Femto cell and Pico cell LTE Capacity Planning

The following steps are procedures for femto cell and Pico cell LTE Capacity Planning

Capacity dimensioning and Planning Analysis

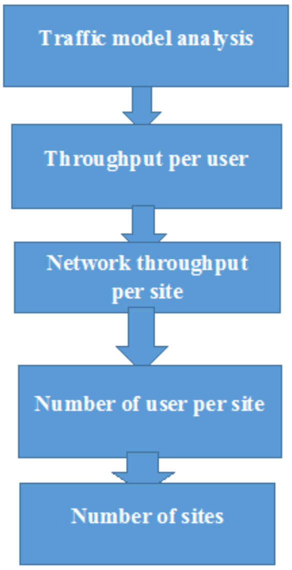

FIGURE 4.1: capacity planning steps

The daily traffic can be estimated as a percentage of the busy hour traffic. In this thesis design we assume the busy hour traffic is 2.5 % the daily traffic. Three types of service packages are provided, golden service package, silver service package, and bronze service package, each service has its own quality, the month service package, the DL peak data rates, and the package percentage, all of these characteristics are shown in table 4.2. The traffic ratio of the DL in terms of the total traffic is

PackageType	FemtoMonthservicepackage(GB)	PicoM.ser.pack(GB)	Per.tage
Gold	50	50	10 %
Sliver	40	40	40 %
Bronze	10	10	50 %

Table 4.3: Femto cell and pico cell LTE users' category.

chosen to be 80% for DL. The number of subscribers must be specified in order to continue the analysis, the subscriber's number for femto cell indoor Auto CAD data base with G+3 building is considered to be 720.

Package type	Avg.throughput @BH per user (kbps),DL
Gold	92.59
Silver	74.07
Bronze	18.518

TABLE 4.4: Total Average throughput per subscriber @BH.

Firstly the total average throughput per subscriber must be calculated in order to calculate the average throughput per site.
Avg.throughput per sub @BHDL(Kbps)=

$$(Monthlyser.pack * (8bit)/byte * BHratio)/(no.ofdaye * timeinsecond) \quad (4.114)$$

Gold custumer Average throughput (DL):
Avg.throughput per sub in BHDL(kbps)=

$$(50 * 10^9 * 8bit/byte * 2.5\%)/(30 * 3600second) = 92.59 \quad (4.115)$$

Silver customer Average throughput(DL):
Avg.throughput per sub in BH(DL)(kbps)=

$$(40 * 10^9 * 8bit/byte * 2.5\%)/(30 * 3600second) = 74.07 \quad (4.116)$$

Bronze customer Average throughput(DL):
Avg.throughput per sub in BH (DL)(Kbps)=

$$(10 * 10^9 * 8bit/byte * 2.5\%)/(30 * 3600second) = 18.51 \quad (4.117)$$

Total Average throughput per sub @BH (kbps)

$$= Sum(Avg.throughputpersub@BHDL * packatepercentage) \tag{4.118}$$

$$92.59 * 10\% + 74.07 * 40\% + 18.518 * 50\% = 48.146 \tag{4.119}$$

The peak average throughput per sector and per site for DL can be calculated as follows. To calculate the peak capacity throughput per sector, first we consider a Pico cell with 20 MHz and femto cell with 10 MHz LTE system with Omni directional antenna configuration, 64QAM and code rate 1: We first calculate the number of resource elements (RE) in a sub-frame (a sub-frame is 1 msec).

$$onesubframepicocell` = 12subcarriers * 100ResourceBlocks * slots = 1,200RE \tag{4.120}$$

Then we calculate the data rate for 64QAM with coding rate 1.

$$peakthroughput = 6bitsper64QAMsymbols * 1,200REssymbols = 7,200bits \tag{4.121}$$

$$peakthroughputinasubframe = 7,200/1msec = 7.2Mbps \tag{4.122}$$

Peak throughput per sector calculation for DL Pico cell communication:
Peak throughput for Pico cell configuration DL= 7.2Mbps

$$onesubframefemtocell` = 12subcarriers * 50ResourceBlocks * 1slots = 600RE \tag{4.123}$$

$$Peakthroughput = 6bitsper64QAMsymbols * 600REssymbols = 3,600bits \tag{4.124}$$

$$peakthroughputinasubframe = 3,600/1msec = 3.6Mbps \tag{4.125}$$

Peak throughput per sector calculation for DL femto cell communication:
Peak throughput for femto cell configuration DL= 3.6 Mbps
Peak throughput per site calculation for DL Pico cell:

$$TotalthroughputpersiteDL = 3 * downlinkdataratepersector \tag{4.126}$$

$$= 3 * 7.2Mbps = 21.6Mbps \tag{4.127}$$

Peak throughput per site calculation for DL femto cell:

$$TotalthroughputpersiteDL = 3 * downlinkdataratepersector \tag{4.128}$$

$$= 3 * 3.6Mbps = 10.8Mbps \tag{4.129}$$

Now, the maximum subscriber's number per site is calculated for DL femto cell and Pico cell then, the lowest is Chosen.
Total number of subscriber per site:
Maximum number of subscriber per site

$$= (TotalAveragethroughputpersite)/(Totalaveragethroughputpersubscriber) \tag{4.130}$$

Maximum number of subscribers per sites DL =
Max.no.of subscriber per sitesDL of pico cell

$$= (21.6Mbps)/48.146Kbps = 448 \tag{4.131}$$

Max.no.of subscriber per sites DL of femto cell

$$= 10.8Mbps/48.146Kbps = 224 \tag{4.132}$$

The Lowest maximum subscriber number per site is femto cell.Then to determine the total number of sites we use femto cell total subscriber no.
Total number of sites calculation for DL femto cell with 720 total subscriber no.and 80 average femto cell user per site and also 224 maximum no.of subscribers per sites.
Total no.of sitesDL femto cell=

$$(Totalsubscriberno.fortherequiredarea)/(Max.no.ofsubscriberpersite) \tag{4.133}$$

$$= 720/224 = 3.2 \tag{4.134}$$

Pico cell total subscriber no.

Total number of sites calculation for DL femto cell with 720 total subscriber no.and 240 average pico cell user per site and also 448 maximum no.of subscribers per sites.

Total no.of sitesDL pico cell=

$$(Totalsubscriberno.fortherequiredarea)/(Max.no.ofsubscriberpersite) \tag{4.135}$$

$$= 720/448 = 1.6 \tag{4.136}$$

The required sites number for a specific indoor Auto CAD building area should be chosen to be the maximum number of sites obtained from coverage and capacity planning calculations to satisfy the traffic requirements of both coverage and capacity. Hence from this thesis total number of sites for femto cell is maximum. According to the results obtained from the coverage and capacity planning analysis, we can take 3 sites that we get from the maximum capacity dimensioning for both indoor radio network planning.

4.4 Pico Cell and femto cell Frequency Planning

The selection of appropriate spectrum depends on many factors, such as the regulatory policy, spectrum fees, existing technologies, and so on Hence in this thesis design we select 1800MHz for Pico cell and femto cell band to use dual band [37].

Pico and femto cell band	Uplink	Downlink	Duplexing mode
1	1920-1980 MHz	2110-2170 MHz	FDD
2	1850-1910 MHz	1930-1990 MHz	FDD
3	1710-1785 MHz	1805-1880 MHz	FDD
4	1710-1755MHz	2110-2155MHz	FDD
5	824-849 MHz	869-894MHz	FDD
4	2500-2570 MHz	2620-2690 MHz	FDD
5	880- 915 MHz	925-960MHz	FDD
6	830-840 MHz	835-875 MHz	FDD
7	2500-2700MHz	2620-2690MHz	FDD
8	880-915 MHz	925-960MHz	FDD
9	1749.9-1452.9MHz	1849.5-1879.5MHz	FDD
10	1710-1770 MHz	2110-2110MHz	FDD
11	1427.9-1452.9MHz	1775.9-1500.9MHz	FDD
12	698-716 MHz	728-746MHz	FDD
13	777-787 MHz	746-756MHz	FDD
14	788-798 MHz	758-768MHz	FDD
17	704-716 MHz	734-746MHz	FDD
18	815-830MHz	860-875MHz	FDD
19	830-845MHz	875-890 MHz	FDD
20	832-862 MHz	791-821 MHz	FDD
21	1447.9-1462.9MHz	1491.9-1510.9 MHz	FDD
22	3410-3490MHz	3510-3590 MHz	FDD
23	2000-2020MHz	2180-2200 MHz	FDD
24	1626.5 -1600.5MHz	1525-1559 MHz	FDD

TABLE 4.5: pico cell and femto cell frequency band.

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Chapter 5

Result and Discussion

5.1 Comparison of propagation models

Figure 5.1 is a mat lab simulation to compare and contrast among Empirical propagation models which is important to select proper propagation model for coverage planning. We compared modified free space model, Motley-Keenan Model (MK), COST-Multi-Wall Model (MW) and ITU Indoor propagation model for Pico cell, and femto cell. By considering the worst case scenario we chose Motely –Keenan Model, ITU Model and COST-Multi-Wall for femto cell 4G indoor radio network planning that shown from the simulation result.
Here the selection is based on which propagation model reads maximum path loss at a certain calculated radius. And this is because to minimize signal degradation at the edge of the cell and to get better signal coverage. In this part we shall discuss the simulation results of indoor femto cell LTE coverage and capacity planning using win prop simulation software based on the analytically results obtained from coverage and capacity estimation.
This indoor radio network planning simulation is intended to carry out the maximum calculated path loss between the transmitter and receiver, the appropriate propagation modeling, signal level, antenna height and others for coverage prediction, due to UL limited femto cell network system the DL throughput for capacity

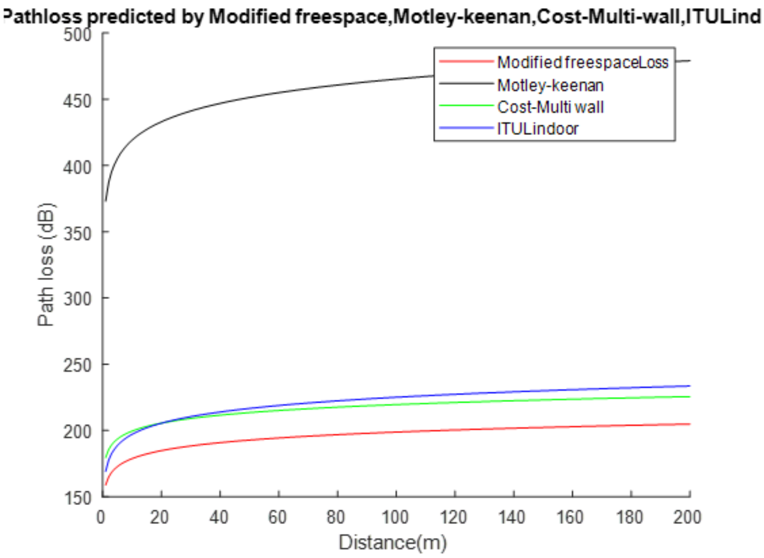


FIGURE 5.1: Comparison of indoor propagation models.

evaluation, and after indoor radio network planning coverage and capacity site count and modeling to determine the maximum site layout within the Auto cad design below.

Data base: By win prop software the wallman is used to simplify the building

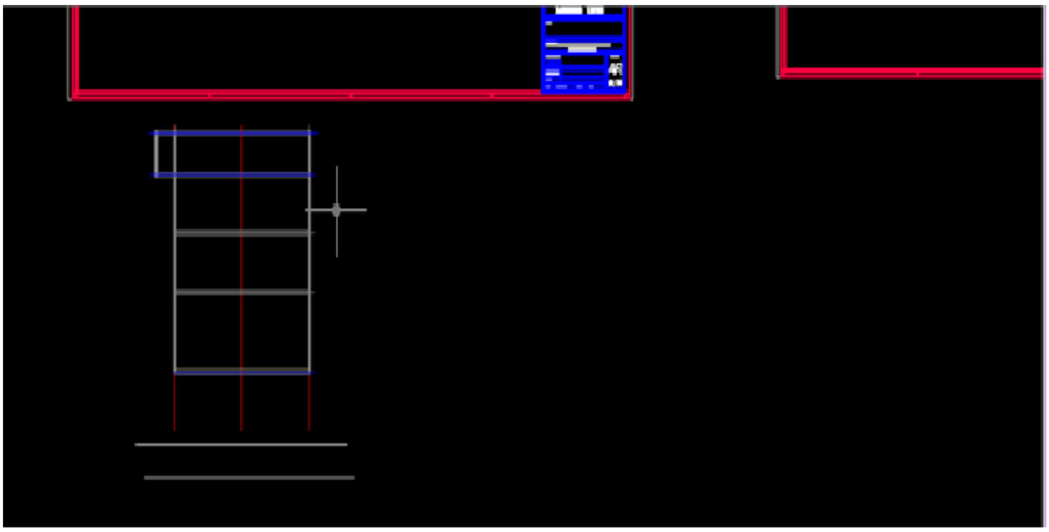


FIGURE 5.2: Auto Cad Design for G+3 Building .

into different pieces of 2 Dimensional rectangular shape.

Site Layout : After importing the Auto cad into the win prop software tool we

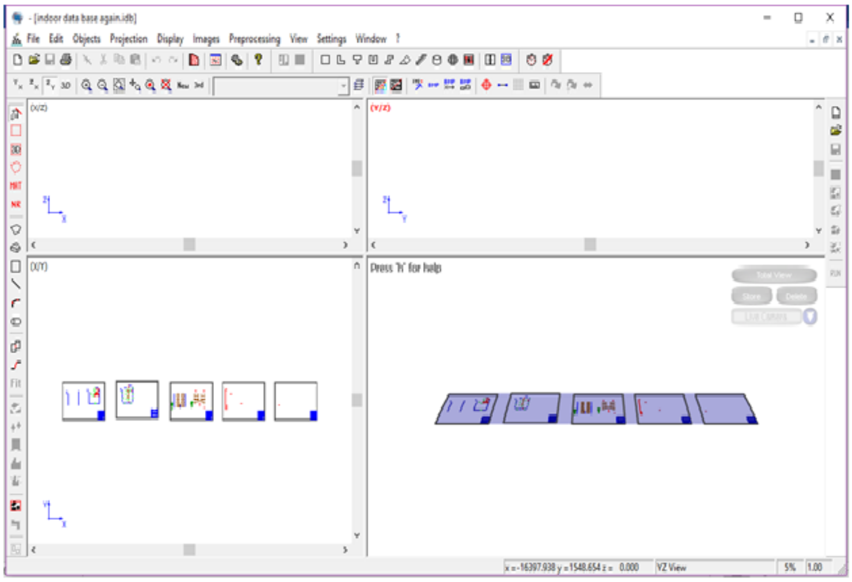


FIGURE 5.3: data base of the Auto Cad with wall man

started by selecting the Area of planning which was chosen according to the selected database.

Win prop includes integrated single site indoor radio network design capabilities for both femto cell 3GPP (LTE) and 3GPP2 (CDMA/LTE) technology streams. It provides operators and vendors with a powerful framework for designing and optimizing current and future integrated indoor-technology networks.

Win prop supports the latest technology advances such as small cells. We are created indoor femto cell base stations based on the calculated coverage and capacity site count by considering different dimensioning parameters shown in chapter three.

The indoor radio network sites within the cell area has different transmitter colors and it shows the number of designed indoor radio access technologies that will be deployed in the future, and each technology is marked by different transmitter as shown in figure 5.4

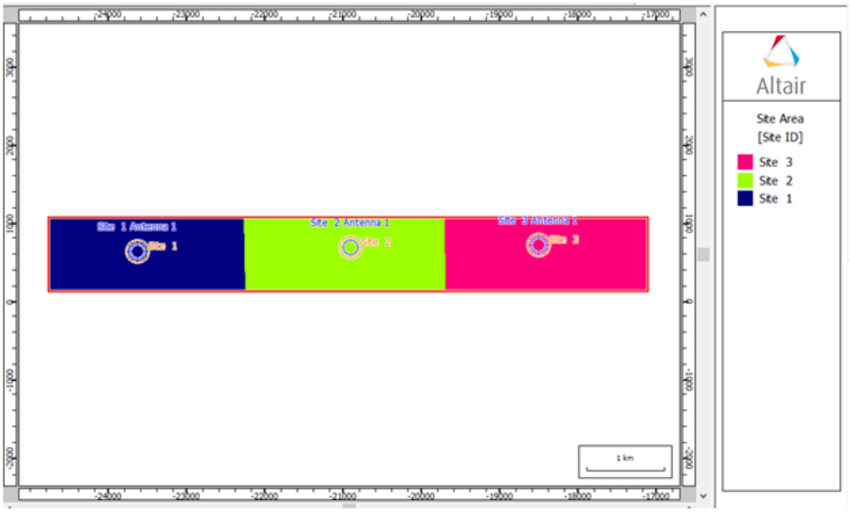


FIGURE 5.4: site area of the building.

5.2 Performance Evaluation of Planned femto cell Network

5.2.1 Fem to cell Site 1 antenna 1 performance analysis for designed network

5.2.1.1 Fem to cell Site 1 antenna 1 Coverage Prediction by power level

A coverage prediction by power level that shows in figure 5.5 tells us the prediction of the best signal strength at each site within Omni directional antenna. This signal prediction result have acceptable coverage as we observe from the simulation result below.

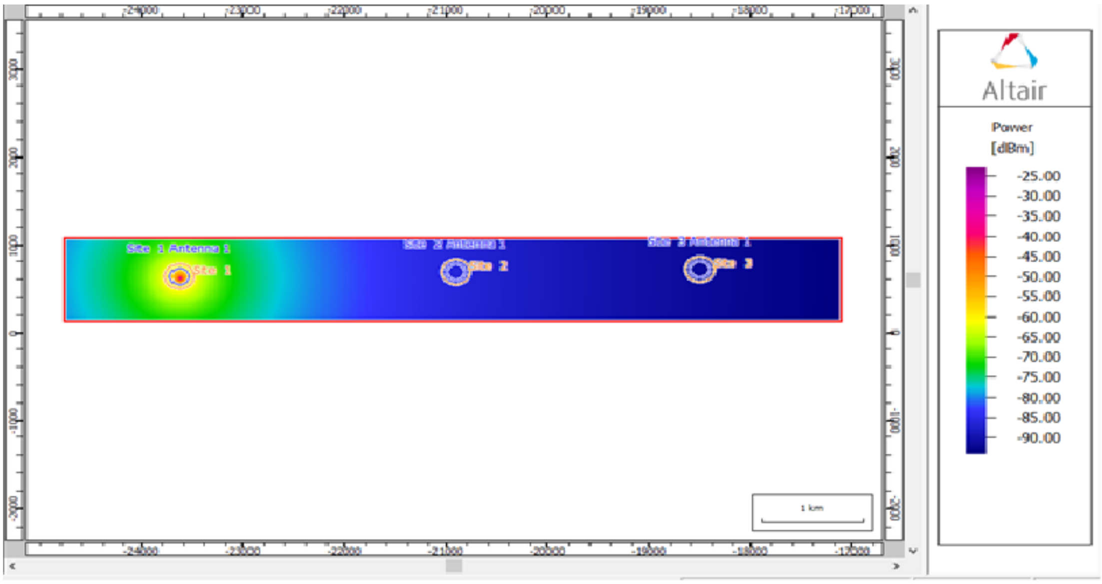


FIGURE 5.5: femto cell Coverage Prediction by power level .

5.2.1.2 Comulative Probability of Femto cell Coverage area with power level

The cumulative probability analysis result shows comparison of coverage area versus best signal strength value. The analysis result shown in figure 5.5 and 5.6 is that more areas within the site1 antenna1 area are covered by strong power level and its power values range from negative 60dBm to 0 dBm and also other areas are covered by acceptable power level when we compare our design receiver sensitivity signal level to - 100dBm.

5.2.1.3 femto cell coverage area with path loss

Win prop is a tool for the design and simulation of wireless systems. It predicts the performance of indoor radio link by using information from the designed network and a database of the building. During the simulation, it checks the line of sight and calculates the path loss. The simulation result in figure 5.8 below justifies that at our designed cell radius we can get an acceptable signal level which is better

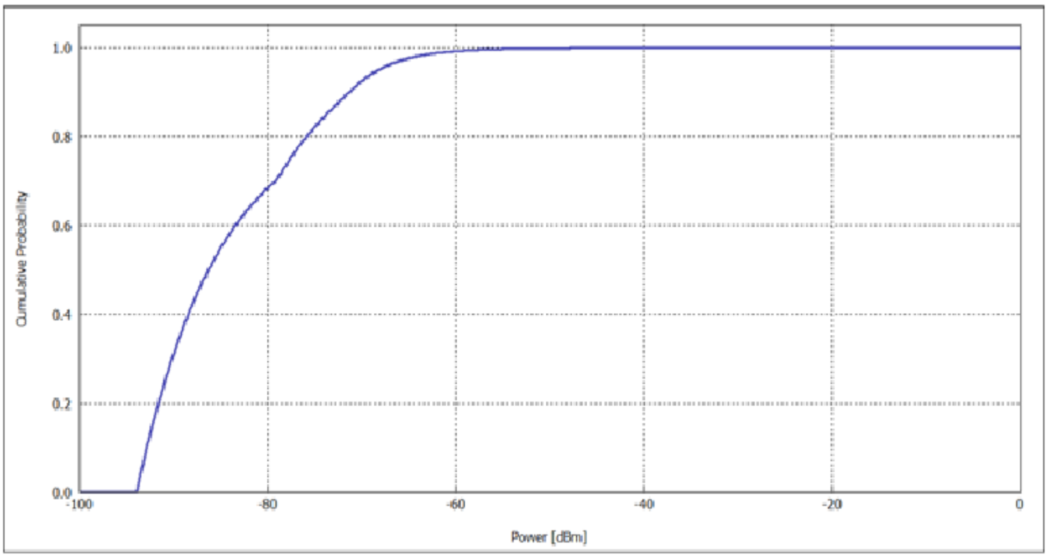


FIGURE 5.6: femto cell Coverage area with cumulative Probablity Vs power..

```
Statistical information:
Minimum value                              : -93.870 dBm
Maximum value                              : -23.130 dBm
Mean value (lin)                           : -83.703 dBm
Mean value (log)                           : -70.140 dBm
Mean of absolute values (lin)              : 83.703 dBm
Mean of absolute values (log)              : 70.140 dBm
Squared mean (lin)                         : 7077.848 (dBm)²
Squared mean (log)                         : -102.595 (dBm)²
Standard deviation (lin)                   : 8.462 dBm
Standard deviation (log)                   : -51.298 dBm
Number of pixels (with value)              : 7222314
Number of pixels (total)                   : 7222314

Computation:
Creation date                              : Oct. 10, 2019
Creation time                              : 06:42:49 am
Computation time (incl. common parts)      : 16 min 33 s  (993 s)
Computation time (only this transmitter)   : 16 min 32 s  (992 s)

Databases:
..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)

Prediction area:
Lower left corner                          : (-24762.4302, 119.7601, 1.5000)
Upper right corner                         : (-17095.4302, 1061.7601, 1.5000)
Resolution                                 : 1.000 m

Transmitter 1 (Site  1 Antenna 1):
Coordinates                                : (-23628.4700, 626.6000, 2.5000 m)
Frequency (used in propagation models)     : 1800.000 MHz
Frequency (used in propagation models)     : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power)  : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)              : Isotropical Radiator
Antenna Gain                               : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)
```

FIGURE 5.7: Statistical information of power level.

than our receiver sensitivity signal level, it implies the signal can fully serve a user at this particular point. And the cumulative probability is shown in figure 5.9

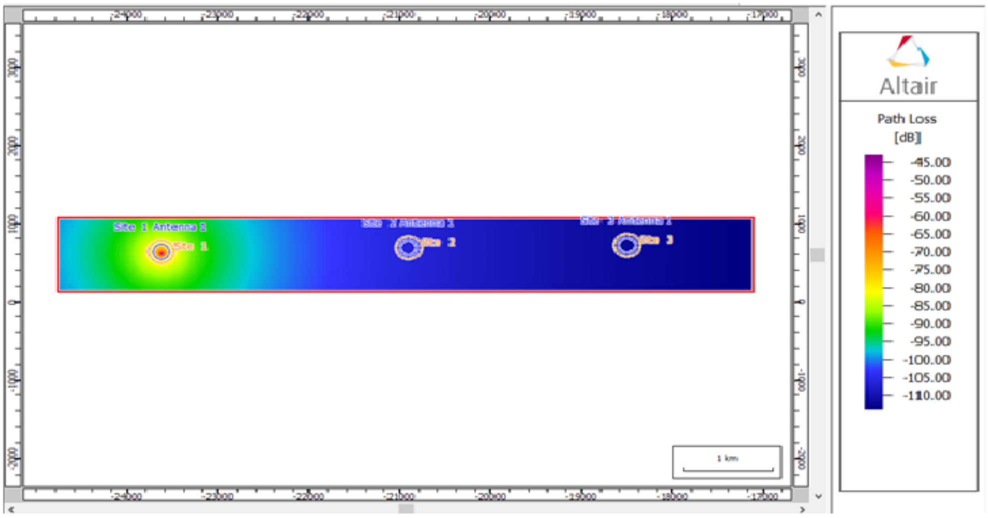


FIGURE 5.8: femto cell Site1 antenna 1 path loss.

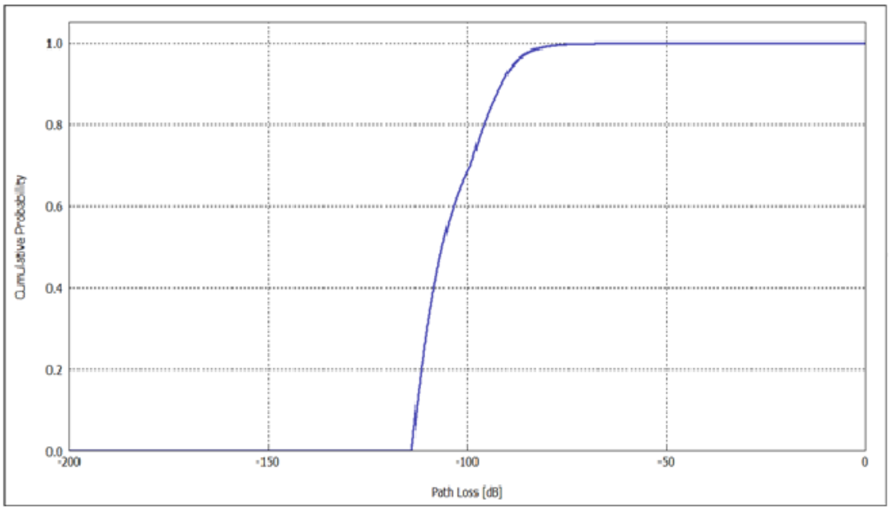
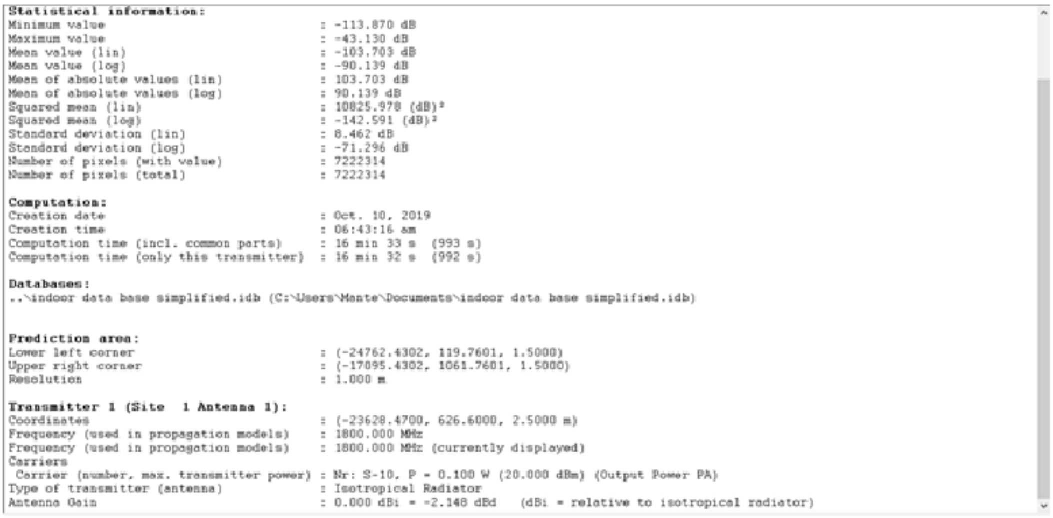


FIGURE 5.9: femto cell site 1 antenna 1 cumulative Probablity Vs path loss. .

5.2.1.4 field strength of femto cell

Femto cell coverage prediction by field strength level shown in figure 5.11 shows the prediction of the best signal strength at each pixel within the computation site. This signal prediction simulation result are acceptable, value when we see result in its legend.



Statistical information:
Minimum value : -113.870 dB
Maximum value : -43.130 dB
Mean value (lin) : -103.703 dB
Mean value (log) : -90.139 dB
Mean of absolute values (lin) : 103.703 dB
Mean of absolute values (log) : 90.139 dB
Squared mean (lin) : 10825.978 (dB)²
Squared mean (log) : -142.591 (dB)²
Standard deviation (lin) : 8.462 dB
Standard deviation (log) : -71.296 dB
Number of pixels (with value) : 7222314
Number of pixels (total) : 7222314

Computation:
Creation date : Oct. 10, 2019
Creation time : 06:43:16 am
Computation time (incl. common parts) : 16 min 33 s (993 s)
Computation time (only this transmitter) : 16 min 32 s (992 s)

Databases:
..\indoor data base simplified.idb (C:\Users\Monte\Documents\indoor data base simplified.idb)

Prediction area:
Lower left corner : (-24762.4302, 119.7601, 1.5000)
Upper right corner : (-17095.4302, 1061.7601, 1.5000)
Resolution : 1.000 m

Transmitter 1 (Site 1 Antenna 1):
Coordinates : (-23628.4700, 626.6000, 2.5000 m)
Frequency (used in propagation models) : 1800.000 MHz
Frequency (used in propagation models) : 1800.000 MHz (currently displayed)
Carriers
Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna) : Isotropical Radiator
Antenna Gain : 0.000 dBi = -2.148 dBd (dBi = relative to isotropical radiator)

FIGURE 5.10: Statistical information of path loss .

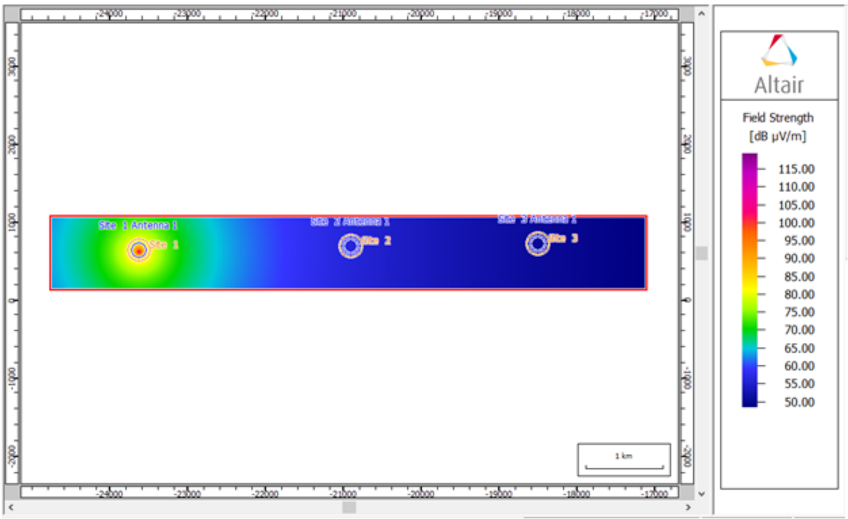


FIGURE 5.11: field strength of femto cell .

5.2.1.5 Cumulative Probability femto cell coverage with field strength

The cumulative probability statistical result shows comparison of coverage area versus best signal strength value, and its statistical result shown in figure 5.13 It shows that most areas within the computation sites are covered by strong signal level and its signal values ranges from 95 to 119.16 [dBuV/m], and also the rest areas are covered by acceptable signal value when we see our design receiver sensitivity signal level 48.43[dBuV/m]

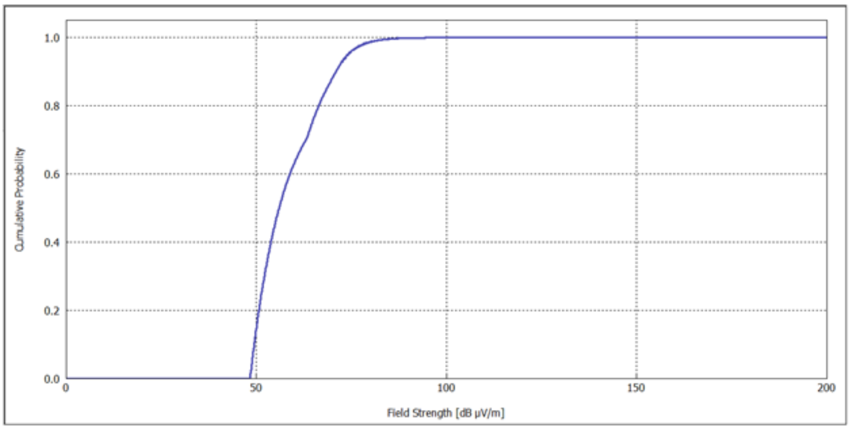


Figure 5.12: femto cell cumulative probability Vs field Strength.

```
Statistical information:
Minimum value                               : 48.430 dB µV/m
Maximum value                               : 119.160 dB µV/m
Mean value (lin)                            : 58.596 dB µV/m
Mean value (log)                            : 63.839 dB µV/m
Mean of absolute values (lin)               : 58.596 dB µV/m
Mean of absolute values (log)               : 63.839 dB µV/m
Squared mean (lin)                          : 3505.084 (dB µV/m)²
Squared mean (log)                          : 144.319 (dB µV/m)²
Standard deviation (lin)                    : 8.461 dB µV/m
Standard deviation (log)                    : 71.468 dB µV/m
Number of pixels (with value)               : 7222314
Number of pixels (total)                    : 7222314

Computation:
Creation date                               : Oct. 10, 2019
Creation time                               : 06:42:25 am
Computation time (incl. common parts)       : 16 min 33 s  (993 s)
Computation time (only this transmitter)    : 16 min 32 s  (992 s)

Databases:
..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)

Prediction area:
Lower left corner                           : (-24762.4302, 119.7601, 1.5000)
Upper right corner                          : (-17095.4302, 1061.7601, 1.5000)
Resolution                                  : 1.000 m

Transmitter 1 (Site  1 Antenna 1):
Coordinates                                 : (-23628.4700, 626.6000, 2.5000 m)
Frequency (used in propagation models)      : 1800.000 MHz
Frequency (used in propagation models)      : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power)   : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)               : Isotropical Radiator
Antenna Gain                                : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)
```

Figure 5.13: Statistical information of femto cell with field strength

5.2.2 Femto cell Site 2 antenna 1 performance analysis for designed network

5.2.2.1 Femto cell Coverage Prediction by power level

A coverage prediction by power level that shown in figure 5.14 tells us the prediction of the best Signal strength at each edge within the designed indoor computation site. The simulation power Level values are greater than our design receiver sensitivity power value.

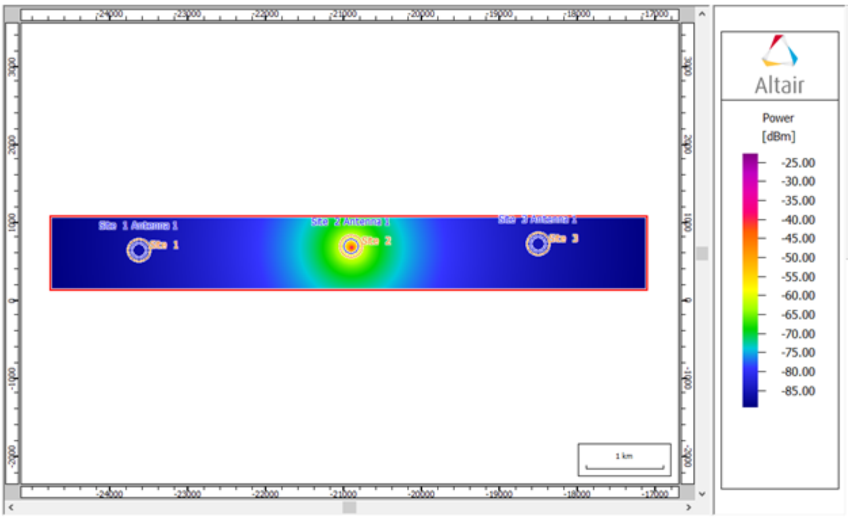


FIGURE 5.14: femto cell site 2 antenna 1 power level

5.2.2.2 femto cell cumulative probability for power level

The statistical result shows comparison of coverage area versus best signal strength value, as shown in figure 5.16. Almost 563.55mˆ2 area within the computation site are covered by -25 dBm strong signal level and the rest 4,311.45 mˆ2 areas are covered by 25 to 89.36 dBm signal value which is better signal strength than our calculated receiver sensitivity signal value.

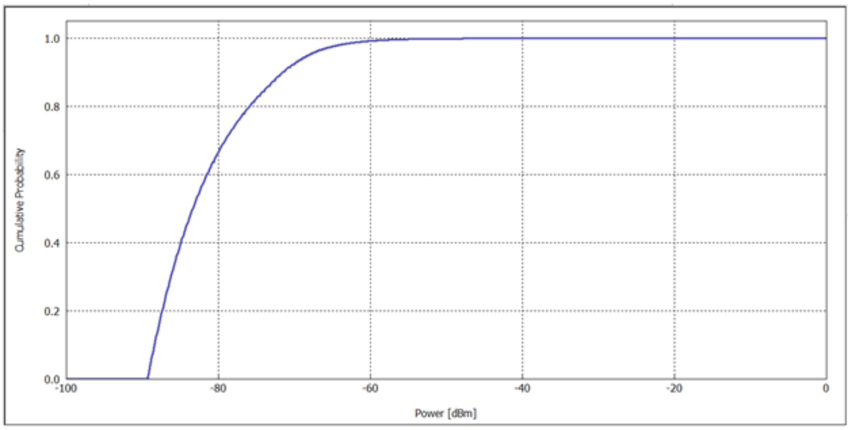
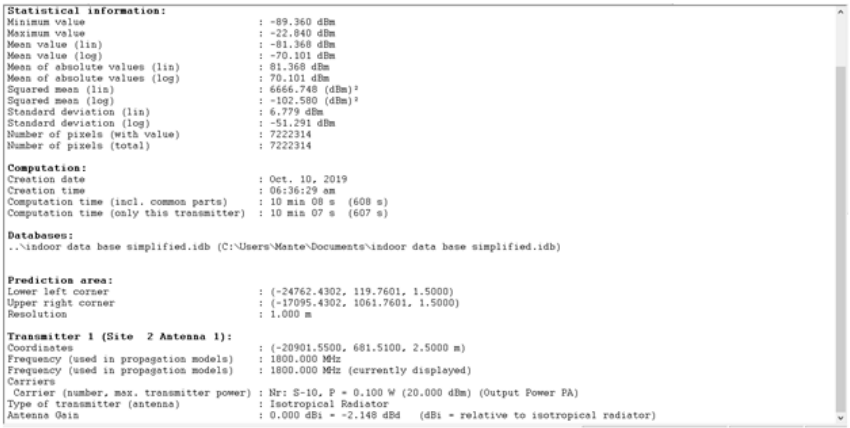


FIGURE 5.15: femto cell cumulative probability Vs power.



Statistical information:
Minimum value : -89.360 dBm
Maximum value : -22.840 dBm
Mean value (lin) : -81.368 dBm
Mean value (log) : -70.101 dBm
Mean of absolute values (lin) : 81.368 dBm
Mean of absolute values (log) : 70.101 dBm
Squared mean (lin) : 6666.748 (dBm)²
Squared mean (log) : -102.580 (dBm)²
Standard deviation (lin) : 6.779 dBm
Standard deviation (log) : -51.291 dBm
Number of pixels (with value) : 7222314
Number of pixels (total) : 7222314

Computation:
Creation date : Oct. 10, 2019
Creation time : 06:36:29 am
Computation time (incl. common parts) : 10 min 08 s (608 s)
Computation time (only this transmitter) : 10 min 07 s (607 s)

Databases:
..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)

Prediction area:
Lower left corner : (-24762.4302, 119.7601, 1.5000)
Upper right corner : (-17095.4302, 1061.7601, 1.5000)
Resolution : 1.000 m

Transmitter 1 (Site 2 Antenna 1):
Coordinates : (-20901.5500, 681.5100, 2.5000 m)
Frequency (used in propagation models) : 1800.000 MHz
Frequency (used in propagation models) : 1800.000 MHz (currently displayed)
Carriers
Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna) : Isotropical Radiator
Antenna Gain : 0.000 dBi = -2.148 dBd (dBi = relative to isotropical radiator)

FIGURE 5.16: Statistical information of femto cell site2 antenna1 power

5.2.2.3 femto cell coverage prediction by path loss

Figure 5.17 shows femto cell path loss profile view of point analysis between a reference transmitter and receiver. The simulation signals level of the received signal from the selected Site 2 femto cell antenna 1, transmitter is greater than our designed receiver sensitivity signal within 17m designed cell radius. Figure

5.18 shows the cumulative probability results of the path loss profile simulation by considering the acceptable displayed parameters when to compare in our designed parameter results.

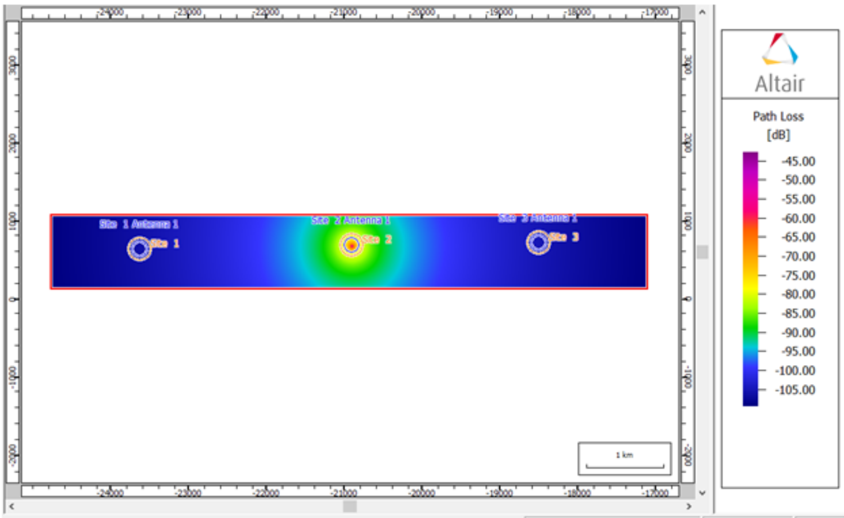


FIGURE 5.17: femto cell Site 2 antenna 1 path loss .

5.2.2.4 femto cell cumulative Probablity Vs path loss

In figure 5.18 the cumulative probability with path loss simulation results shown the range of path loss us compare to the designed network for site2 antenna 1

5.2.2.5 femto cell coverage prediction with field strength

Figure 5.20 simulation results for coverage prediction of femto cell field strength is greater than the designed network. Hence the signal strength is very high us shown in figure 5.21 when the field strength is high

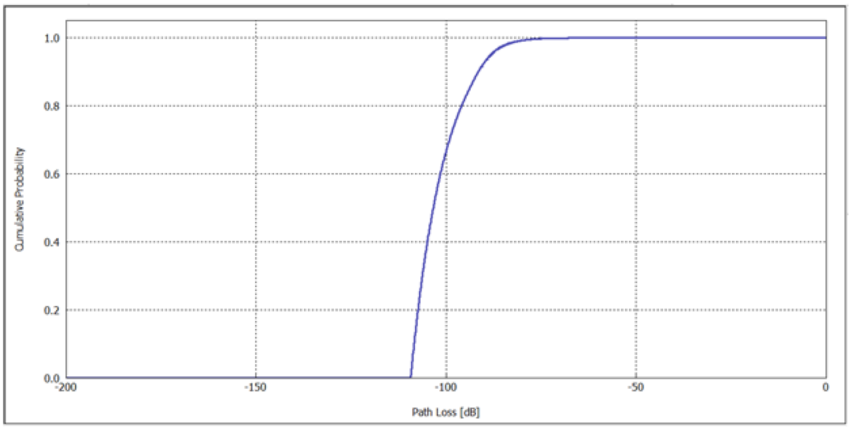
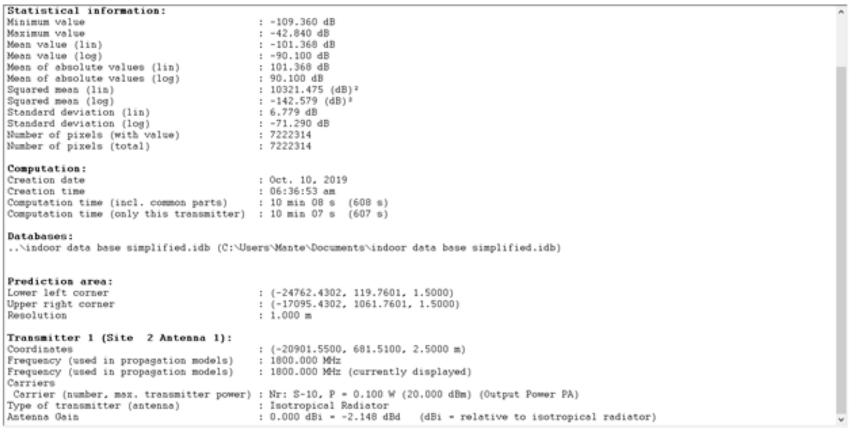


FIGURE 5.18: femto cell cumulative probability Vs path loss .



```
Statistical information:
Minimum value                              : -109.360 dB
Maximum value                              : -42.840 dB
Mean value (lin)                           : -101.368 dB
Mean value (log)                           : -90.100 dB
Mean of absolute values (lin)              : 101.368 dB
Mean of absolute values (log)              : 90.100 dB
Squared mean (lin)                         : 10321.475 (dB)²
Squared mean (log)                         : -142.579 (dB)²
Standard deviation (lin)                   : 6.779 dB
Standard deviation (log)                   : -71.290 dB
Number of pixels (with value)              : 7222314
Number of pixels (total)                   : 7222314

Computation:
Creation date                              : Oct. 10, 2019
Creation time                              : 06:36:53 am
Computation time (incl. common parts)      : 10 min 08 s  (608 s)
Computation time (only this transmitter)   : 10 min 07 s  (607 s)

Databases:
..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)

Prediction area:
Lower left corner                          : (-24762.4302, 119.7601, 1.5000)
Upper right corner                         : (-17095.4302, 1061.7601, 1.5000)
Resolution                                 : 1.000 m

Transmitter 1 (Site  2 Antenna 1):
Coordinates                                : (-20901.5500, 681.5100, 2.5000 m)
Frequency (used in propagation models)     : 1800.000 MHz
Frequency (used in propagation models)     : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power)  : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)              : Isotropical Radiator
Antenna Gain                               : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)
```

FIGURE 5.19: Statistical information site2 antenna1 femto cell with path loss

5.2.2.6 femto cell cumulative probability Vs field strength

The femto cell coverage would be high when the field strength in the simulation results shown so high us compared to the deigned network. Hence the analysis of field strength was very important for coverage planning.

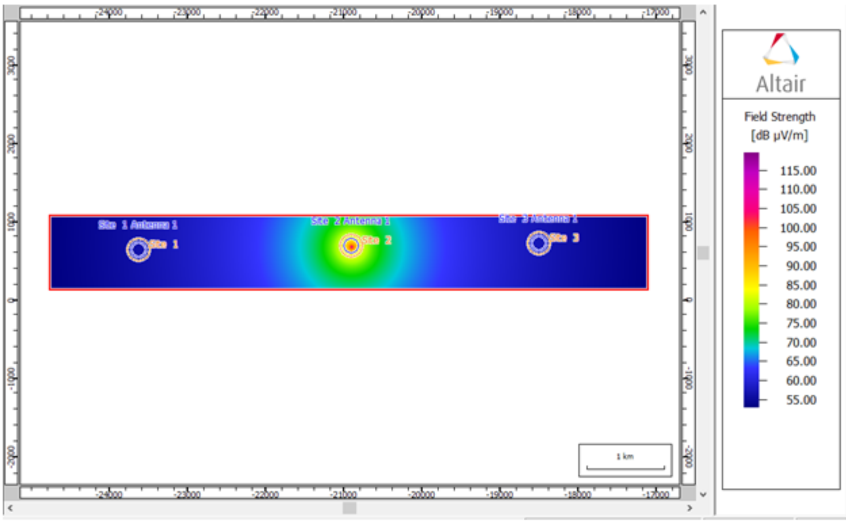


FIGURE 5.20: femto cell site 2 antenna 1 field strength.

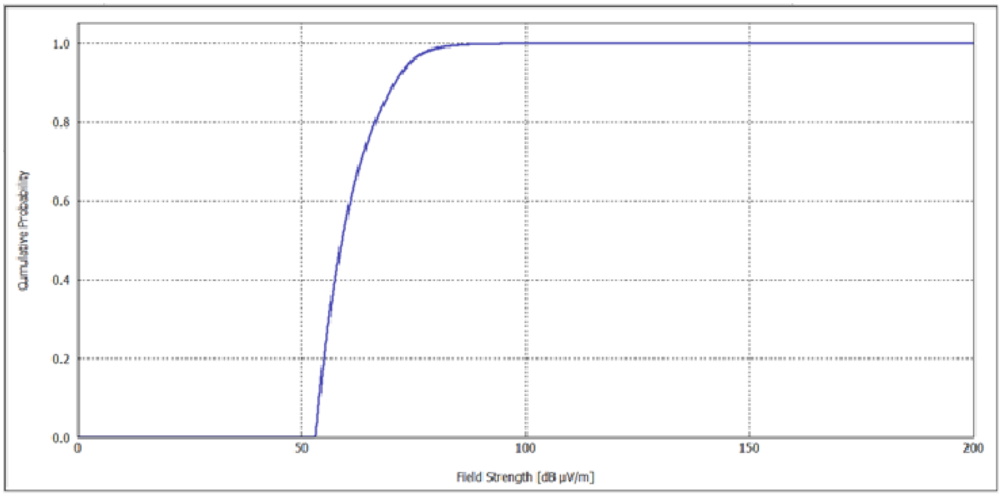
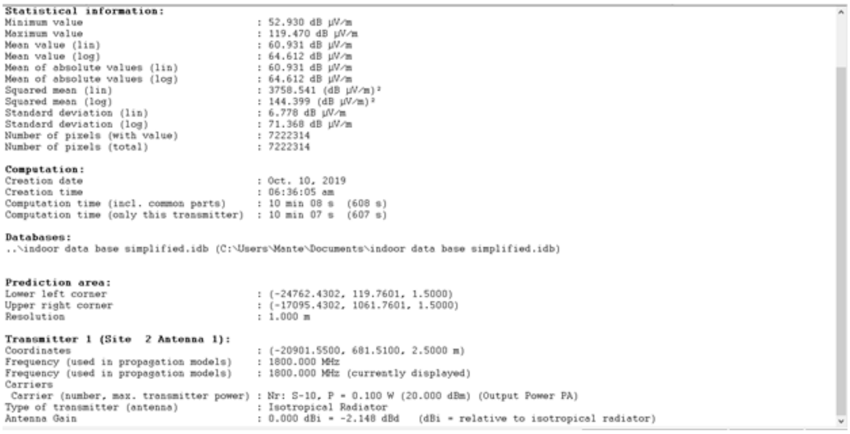


FIGURE 5.21: cumulative probability Vs field strength.



```
Statistical information:
Minimum value                               : 52.930 dB µV/m
Maximum value                               : 119.470 dB µV/m
Mean value (lin)                            : 60.931 dB µV/m
Mean value (log)                            : 64.612 dB µV/m
Mean of absolute values (lin)               : 60.931 dB µV/m
Mean of absolute values (log)               : 64.612 dB µV/m
Squared mean (lin)                          : 3758.541 (dB µV/m)²
Squared mean (log)                          : 144.399 (dB µV/m)²
Standard deviation (lin)                    : 6.778 dB µV/m
Standard deviation (log)                    : 71.368 dB µV/m
Number of pixels (with value)               : 7222314
Number of pixels (total)                    : 7222314

Computation:
Creation date                               : Oct. 10, 2019
Creation time                               : 06:36:05 am
Computation time (incl. common parts)       : 10 min 08 s  (608 s)
Computation time (only this transmitter)    : 10 min 07 s  (607 s)

Databases:
..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)

Prediction area:
Lower left corner                           : (-24762.4302, 119.7601, 1.5000)
Upper right corner                          : (-17095.4302, 1061.7601, 1.5000)
Resolution                                  : 1.000 m

Transmitter 1 (Site  2 Antenna 1):
Coordinates                                 : (-20901.5500, 681.5100, 2.5000 m)
Frequency (used in propagation models)      : 1800.000 MHz
Frequency (used in propagation models)      : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power)   : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)               : Isotropical Radiator
Antenna Gain                                : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)
```

FIGURE 5.22: Statistical information of femto cell site 2 antenna1 field strength

5.2.3 Femto cell Site 3 antenna 1 performance analysis for designed network

5.2.3.1 femto cell site 3 antenna1 coverage prediction with power

Figure 5.23 shown the simulation result's power level are more than the designed network receiver sensitivity. Hence the performance and the QOS would be very high us compared to the designed network for site 3 antenna 1.

5.2.3.2 femto cell site 3 antenna 1 cumulative probability Vs power

In cumulative probability function the power level range would be between the maximum and minimum value to show the simulation results are greater than the designed network from the analysis of the receiver sensitivity us shown figure 5.24

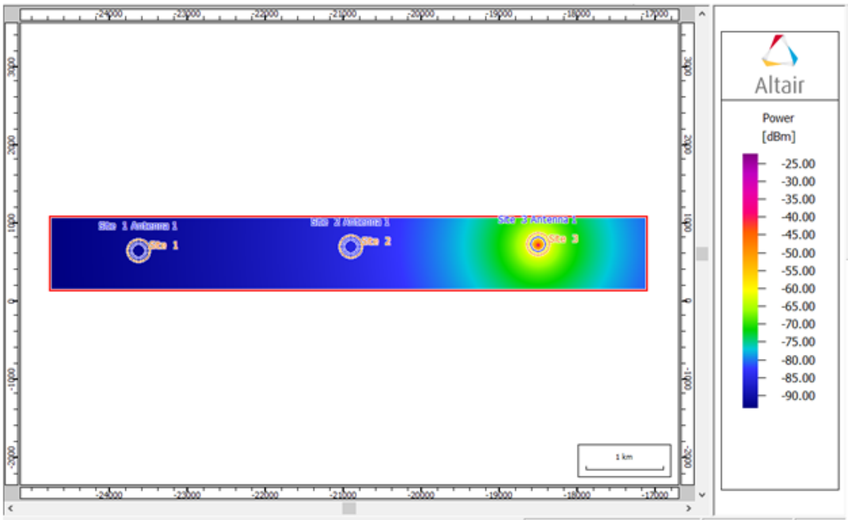


FIGURE 5.23: femto cell site3 antenna1 power level.

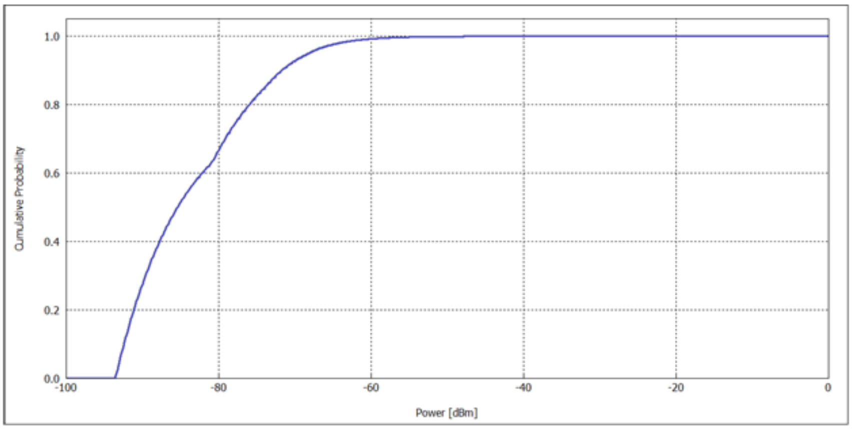


FIGURE 5.24: femto cell site 3 antenna 1 cumulative probability Vs. Power. .

5.2.3.3 femto cell site 3 antenna 1 coverage with path loss

Figure 5.26 simulation results of path loss for femto cell site 3 antenna 1 is greater than the designed network .Hence the network coverage planning is high.

```
Statistical information:
Minimum value                             : -93.510 dBm
Maximum value                             : -22.470 dBm
Mean value (lin)                          : -83.256 dBm
Mean value (log)                          : -70.154 dBm
Mean of absolute values (lin)             : 83.256 dBm
Mean of absolute values (log)             : 70.154 dBm
Squared mean (lin)                        : 6999.099 (dBm)²
Squared mean (log)                        : -102.583 (dBm)²
Standard deviation (lin)                  : 8.217 dBm
Standard deviation (log)                  : -51.292 dBm
Number of pixels (with value)             : 7222314
Number of pixels (total)                  : 7222314

Computation:
Creation date                             : Oct. 10, 2019
Creation time                             : 06:43:55 am
Computation time (incl. common parts)     : 17 min 39 s  (1059 s)
Computation time (only this transmitter)  : 17 min 38 s  (1058 s)

Databases:
..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)

Prediction area:
Lower left corner                         : (-24762.4302, 119.7601, 1.5000)
Upper right corner                        : (-17095.4302, 1061.7601, 1.5000)
Resolution                                : 1.000 m

Transmitter 1 (Site  3 Antenna 1):
Coordinates                               : (-18504.0500, 718.1100, 2.5000 m)
Frequency (used in propagation models)    : 1800.000 MHz
Frequency (used in propagation models)    : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)             : Isotropical Radiator
Antenna Gain                              : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)
```

FIGURE 5.25: Statistical information of femto cell for site 3 antenna 1

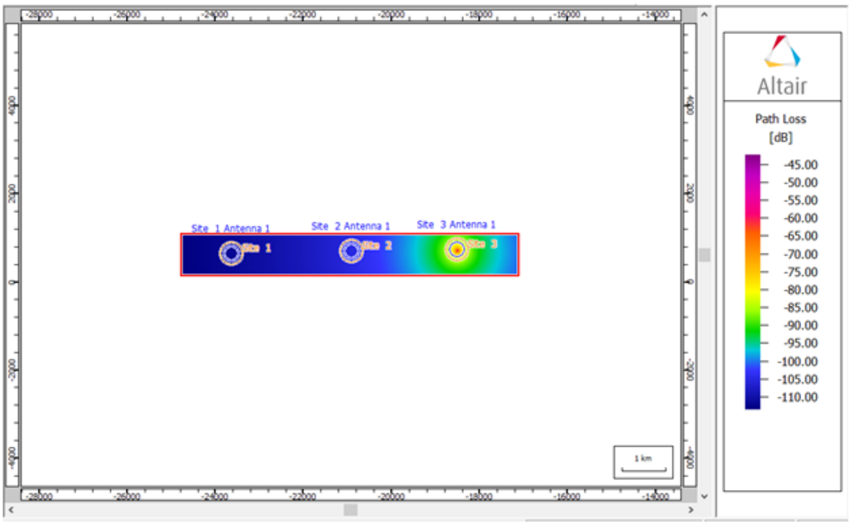


FIGURE 5.26: femto cell site 3 antenna 1 path loss.

5.2.3.4 femto cell site 3 antenna 1 cumulative probability Vs path loss

From figure 5.27 the cumulative probability with path loss shown the range of the simulation result is high us compared to the designed network for site 3 antenna 1.

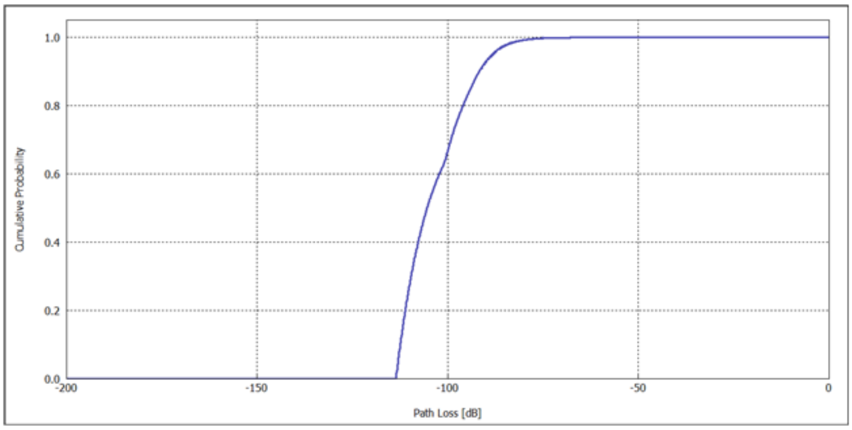
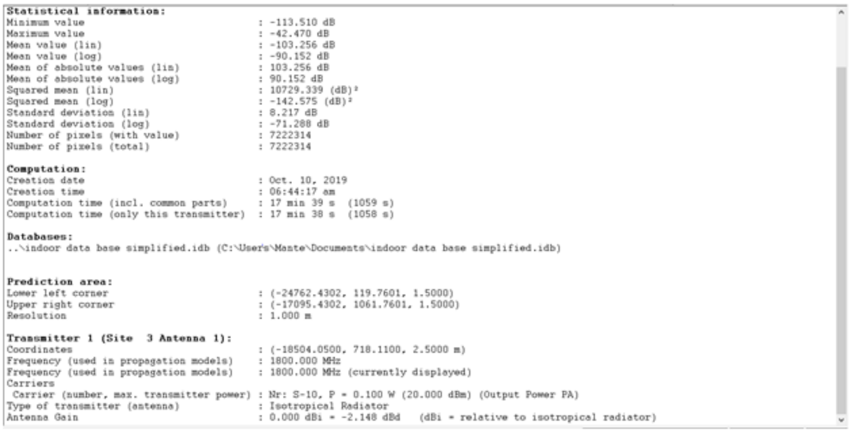


FIGURE 5.27: femto cell site 3 antenna 1 cumulative probability Vs path loss.

.



```
Statistical information:
Minimum value                               : -113.510 dB
Maximum value                               : -42.470 dB
Mean value (lin)                            : -103.256 dB
Mean value (log)                            : -90.152 dB
Mean of absolute values (lin)               : 103.256 dB
Mean of absolute values (log)               : 90.152 dB
Squared mean (lin)                          : 10729.339 (dB)²
Squared mean (log)                          : -142.575 (dB)²
Standard deviation (lin)                    : 8.217 dB
Standard deviation (log)                    : -71.288 dB
Number of pixels (with value)               : 7222314
Number of pixels (total)                    : 7222314

Computation:
Creation date                               : Oct. 10, 2019
Creation time                               : 06:44:17 am
Computation time (incl. common parts)       : 17 min 39 s  (1059 s)
Computation time (only this transmitter)    : 17 min 38 s  (1058 s)

Databases:
..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)

Prediction area:
Lower left corner                           : (-24762.4302, 119.7601, 1.5000)
Upper right corner                          : (-17095.4302, 1061.7601, 1.5000)
Resolution                                  : 1.000 m

Transmitter 1 (Site  3 Antenna 1):
Coordinates                                 : (-18504.0500, 718.1100, 2.5000 m)
Frequency (used in propagation models)      : 1800.000 MHz
Frequency (used in propagation models)      : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power)   : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)               : Isotropical Radiator
Antenna Gain                                : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)
```

FIGURE 5.28: Statistical information of femto cell site 3 antenna 1 with path loss

5.2.3.5 femto cell field strength coverage prediction for site 3 antenna 1

In figure 5.29 the simulation results field strength is high and the signal strength is also high us compared to the designed network .Hence the coverage planning is too high us shown figure 5.29

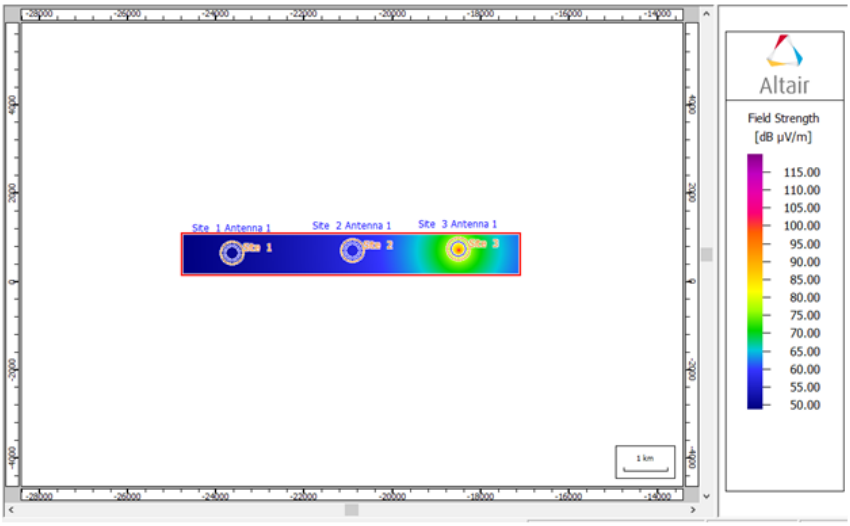


FIGURE 5.29: femto cell site 3 antenna 1 field strength.

5.2.3.6 femto cell site 3 antenna 1 cumulative probability Vs. field strength

Simulation result analysis of femto cell site 3 antenna 1 field strength cumulative probability told us the range of field strength is greater in the simulation results us compared to the designed network us shown in figure 5.30. it is very important to coverage and capacity planning.

5.3 Femto cell Coverage area with Throughput

Downlink throughput coverage predictions calculate and display the channel throughputs and cell capacities based on SNIR and received power calculation for each site. These coverage predictions can also display aggregate cell throughputs. The simulation result determines the total number of symbols in the downlink sub frames from the input parameter tables. Then, Win prop determines the bearer at each pixel and multiplies the bearer efficiency by the number of symbols in

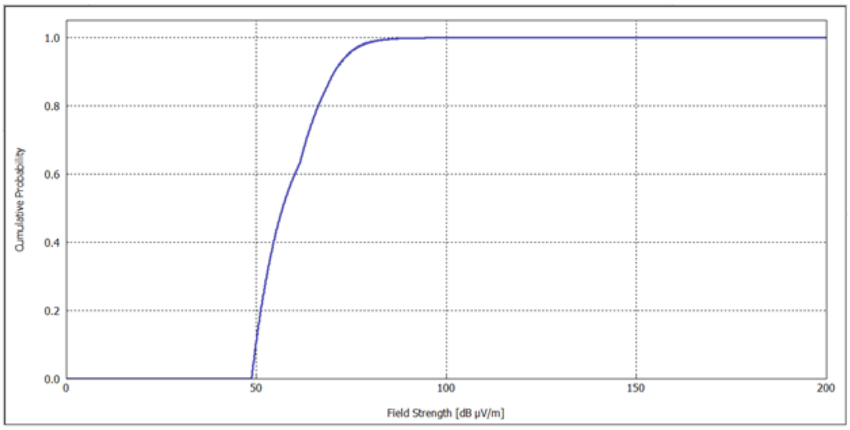


FIGURE 5.30: femto cell site 3 antenna 1 cumulative probability Vs. field strength.

```
Statistical information:
Minimum value                               : 48.800 dB µV/m
Maximum value                               : 119.830 dB µV/m
Mean value (lin)                            : 59.043 dB µV/m
Mean value (log)                            : 63.968 dB µV/m
Mean of absolute values (lin)               : 59.043 dB µV/m
Mean of absolute values (log)               : 63.968 dB µV/m
Squared mean (lin)                          : 3553.625 (dB µV/m)²
Squared mean (log)                          : 144.292 (dB µV/m)²
Standard deviation (lin)                    : 8.217 dB µV/m
Standard deviation (log)                    : 71.429 dB µV/m
Number of pixels (with value)               : 7222314
Number of pixels (total)                    : 7222314

Computation:
Creation date                               : Oct. 10, 2019
Creation time                               : 06:43:34 am
Computation time (incl. common parts)       : 17 min 39 s  (1059 s)
Computation time (only this transmitter)    : 17 min 38 s  (1058 s)

Databases:
..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)

Prediction area:
Lower left corner                           : (-24762.4302, 119.7601, 1.5000)
Upper right corner                          : (-17095.4302, 1061.7601, 1.5000)
Resolution                                  : 1.000 m

Transmitter 1 (Site  3 Antenna 1):
Coordinates                                 : (-18504.0500, 718.1100, 2.5000 m)
Frequency (used in propagation models)      : 1800.000 MHz
Frequency (used in propagation models)      : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power)   : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)               : Isotropical Radiator
Antenna Gain                                : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)
```

FIGURE 5.31: Statistical information of femto cell site 3 antenna 1 field strength

the frame to determine the peak MAC channel throughputs. The cell capacity is equal to channel throughput when the maximum traffic load is set to 100 persons, and is equal to a throughput limited by the maximum allowed traffic loads otherwise. Cell capacities are, therefore, channel throughputs scaled down to respect the maximum traffic load limits. The per-user throughput in DL is calculated by dividing the DL cell capacity by the number of DL users of the serving cell. For femto cell planning the throughput is uplink limited .Hence the simulation result shows the DL individual user throughputs within the indoor area is acceptable us shown figure 5.41.

5.3.1 femto cell network received power for all sites antenna 1

Figure 5.32 shows femto cell profile view of point analysis between a reference transmitter and receiver. The simulation signals level of the received signal from the selected all Sites femto cell antenna 1, transmitter is greater than our designed receiver sensitivity signal within 17m designed cell radius. Hence the QOS is very high as shown from the results Figure 5.33 shows the link budget results of the profile simulation by considering the acceptable displayed parameters when to compare in our designed parameter results.

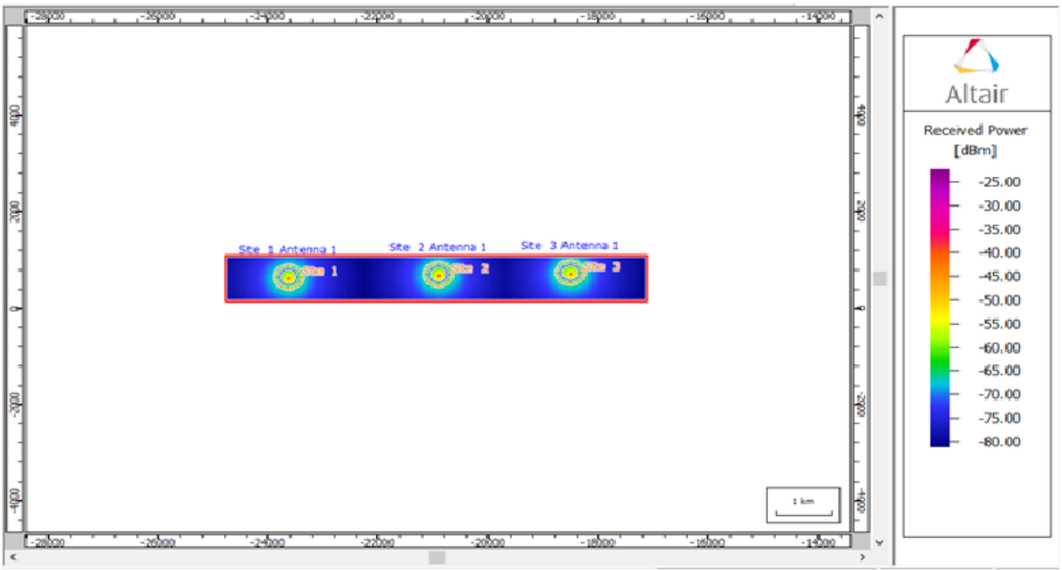


FIGURE 5.32: femto cell network received power for all sites antenna 1

5.3.2 femto cell network cumulative probability Vs received power

The cumulative probability of the following designed network show the received power of the designed network performance is very high for all systems.

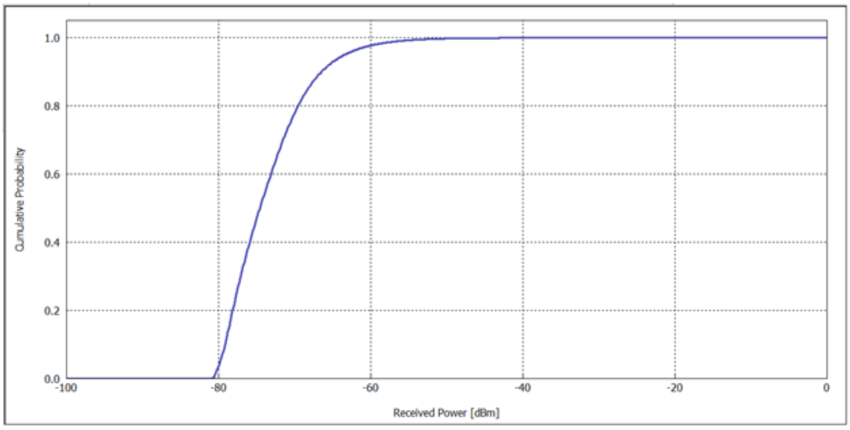


FIGURE 5.33: femto cell network cumulative probability Vs. received power for all sites antenna1.

5.3.3 femto cell network DL:SNIR (best server) for all sites antenna1

The simulation result shown here the down link signal to noise and interference ratio is above the receiver sensitivity for all active femto cell network sites with isotropic Omni directional antenna. The network planning concept of indoor coverage and capacity planning of femto cell and QOS performance would be high us shown in figure 5.35

```
Network Prediction
Program version: 2019.01

Prediction file                          : again femto cell path loss

Statistical information:
Minimum value                            : -81.230 dBm
Maximum value                            : -22.470 dBm
Mean value (lin)                         : -73.404 dBm
Mean value (log)                         : -65.438 dBm
Mean of absolute values (lin)            : 73.404 dBm
Mean of absolute values (log)            : 65.438 dBm
Squared mean (lin)                       : 5416.673 (dBm)²
Squared mean (log)                       : -97.815 (dBm)²
Standard deviation (lin)                 : 5.337 dBm
Standard deviation (log)                 : -48.909 dBm
Number of pixels (with value)            : 7222314
Number of pixels (total)                 : 7223256

Computation:
Creation date                            : Oct. 10, 2019
Creation time                            : 06:48:04 am
```

```
Creation time                            : 06:48:04 am

Databases:
..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)


Prediction area:
Lower left corner                        : (-24762.43, 119.76, 1.50)
Upper right corner                       : (-17094.43, 1061.76, 1.50)
Resolution                               : 1.000 m

Transmitter 1 (Site  3 Antenna 1):
Coordinates                              : (-18504.05, 718.11, 2.50 m)
Frequency (used in propagation models)   : 1800.000 MHz
Frequency (used in propagation models)   : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)            : Isotropical Radiator
Antenna Gain                             : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)

Transmitter 2 (Site  2 Antenna 1):
Coordinates                              : (-20901.55, 681.51, 2.50 m)
Frequency (used in propagation models)   : 1800.000 MHz
Frequency (used in propagation models)   : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)            : Isotropical Radiator
Antenna Gain                             : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)

Transmitter 3 (Site  1 Antenna 1):
Coordinates                              : (-23628.47, 626.60, 2.50 m)
Frequency (used in propagation models)   : 1800.000 MHz
Frequency (used in propagation models)   : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)            : Isotropical Radiator
Antenna Gain                             : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)
```

FIGURE 5.34: Statistical information of femto cell network received power for all site antenna 1

5.3.4 femto cell network cumulative probability Vs DL:SINR for all sites antenna 1

In the cumulative probability Vs .DL: SINR is shown that the simulation result is greater than the designed network us shown figure 5.36.

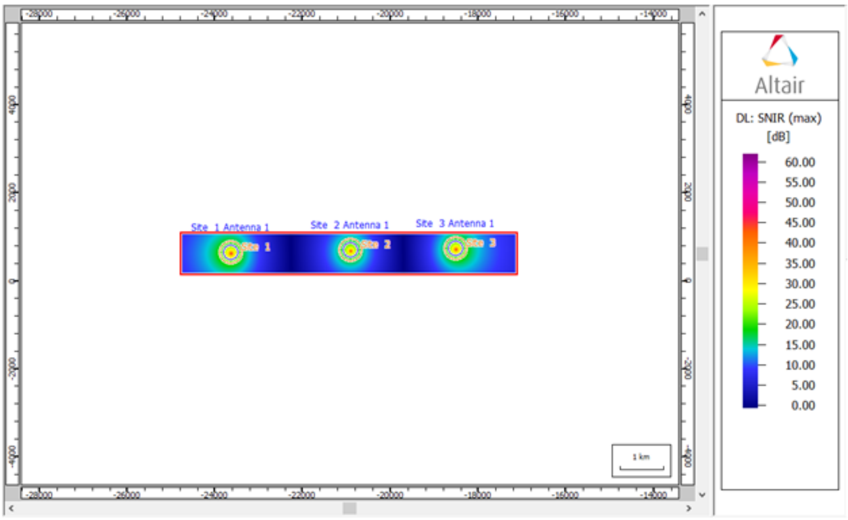


FIGURE 5.35: femto cell network DL: SNIR for all sites antenna 1.

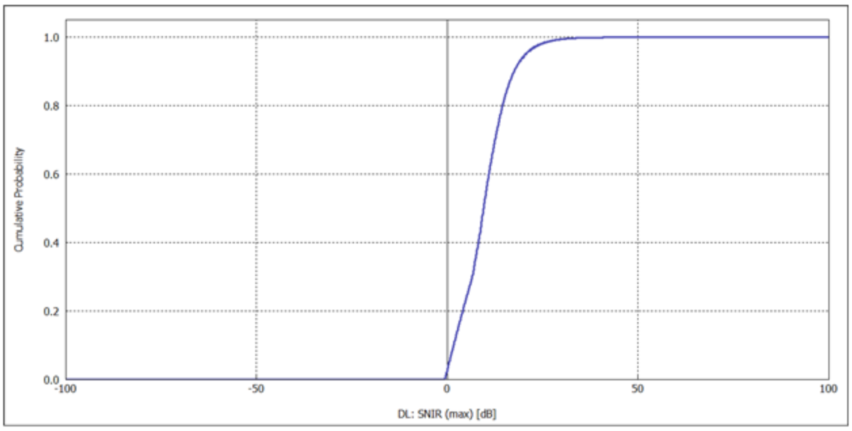


FIGURE 5.36: femto cell network cumulative probability Vs SINR for all sites antenna .

5.3.5 femto cell network DL:SINR of carrier 10 for all sites antenna 1

Figure 5.38 simulation results of signal to noise and interference ratio in the carrier 10 is greater than the server signal to noise and interference ratio. When we designed this thesis with carrier10 for all sites the maximum signal to noise and

```
Network Prediction
Program version: 2019.01

Prediction file                           : again femto cell path loss

Statistical information:
Minimum value                             : -0.660 dB
Maximum value                             : 61.810 dB
Mean value (lin)                          : 9.899 dB
Mean of absolute values (lin)             : 9.912 dB
Squared mean (lin)                        : 136.240 (dB)²
Standard deviation (lin)                  : 6.185 dB
Number of pixels (with value)             : 7222314
Number of pixels (total)                  : 7223256

Computation:
Creation date                             : Oct. 10, 2019
Creation time                             : 06:48:03 am
```

```
Creation time                             : 06:48:03 am

Databases:
..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)


Prediction area:
Lower left corner                         : (-24762.43, 119.76, 1.50)
Upper right corner                        : (-17094.43, 1061.76, 1.50)
Resolution                                : 1.000 m

Transmitter 1 (Site  3 Antenna 1):
Coordinates                               : (-18504.05, 718.11, 2.50 m)
Frequency (used in propagation models)    : 1800.000 MHz
Frequency (used in propagation models)    : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)             : Isotropical Radiator
Antenna Gain                              : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)

Transmitter 2 (Site  2 Antenna 1):
Coordinates                               : (-20901.55, 681.51, 2.50 m)
Frequency (used in propagation models)    : 1800.000 MHz
Frequency (used in propagation models)    : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)             : Isotropical Radiator
Antenna Gain                              : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)

Transmitter 3 (Site  1 Antenna 1):
Coordinates                               : (-23628.47, 626.60, 2.50 m)
Frequency (used in propagation models)    : 1800.000 MHz
Frequency (used in propagation models)    : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)             : Isotropical Radiator
Antenna Gain                              : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)
```

FIGURE 5.37: Statistical Information of femto cell network DL: SINR for all sites antenna 1

interference ratio was high us compare to the server SNIR.Hence the simulation results of the receiver sensitivity greater than the designed network with best coverage, capacity and QOS in the planned network.

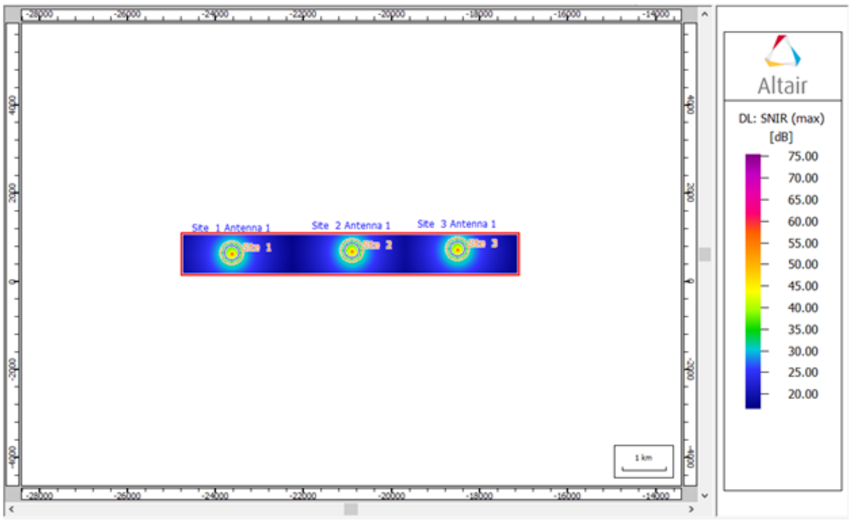


FIGURE 5.38: femto cell carrier 10 DL:SNIR all sites antenna 1

5.3.6 femto cell network cumulative probability Vs. DL:SNIR of carrier 10 for all sites antenna 1

The simulation results in cumulative probability would be high with carrier signal us compared to the server shown in figure 5.39

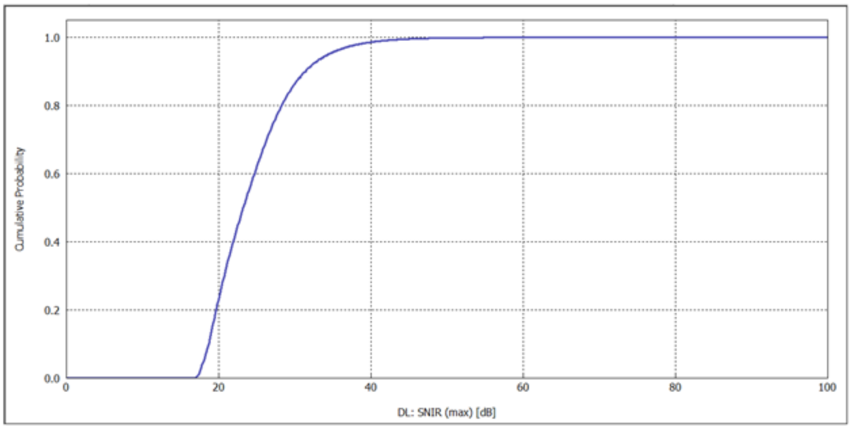


FIGURE 5.39: femto cell network cumulative probability Vs.DL: SNIR

```
Network Prediction
Program version: 2019.01

Prediction file                          : again femto cell path loss

Statistical information:
Minimum value                            : 16.590 dB
Maximum value                            : 75.340 dB
Mean value (lin)                         : 24.412 dB
Mean of absolute values (lin)            : 24.412 dB
Squared mean (lin)                       : 624.430 (dB)²
Standard deviation (lin)                 : 5.337 dB
Number of pixels (with value)            : 7222314
Number of pixels (total)                 : 7223256

Computation:
Creation date                            : Oct. 10, 2019
Creation time                            : 06:48:09 am
```

```
Creation time                            : 06:48:09 am

Databases:
..\..\indoor data base simplified.idb (C:\Users\Mante\Documents\indoor data base simplified.idb)


Prediction area:
Lower left corner                        : (-24762.43, 119.76, 1.50)
Upper right corner                       : (-17094.43, 1061.76, 1.50)
Resolution                               : 1.000 m

Transmitter 1 (Site  3 Antenna 1):
Coordinates                              : (-18504.05, 718.11, 2.50 m)
Frequency (used in propagation models)   : 1800.000 MHz
Frequency (used in propagation models)   : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)            : Isotropical Radiator
Antenna Gain                             : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)

Transmitter 2 (Site  2 Antenna 1):
Coordinates                              : (-20901.55, 681.51, 2.50 m)
Frequency (used in propagation models)   : 1800.000 MHz
Frequency (used in propagation models)   : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)            : Isotropical Radiator
Antenna Gain                             : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)

Transmitter 3 (Site  1 Antenna 1):
Coordinates                              : (-23628.47, 626.60, 2.50 m)
Frequency (used in propagation models)   : 1800.000 MHz
Frequency (used in propagation models)   : 1800.000 MHz (currently displayed)
Carriers
 Carrier (number, max. transmitter power) : Nr: S-10, P = 0.100 W (20.000 dBm) (Output Power PA)
Type of transmitter (antenna)            : Isotropical Radiator
Antenna Gain                             : 0.000 dBi = -2.148 dBd   (dBi = relative to isotropical radiator)
```

FIGURE 5.40: Statistical information of femto cell of carrier 10 DL: SNIR for all sites antenna 1

5.3.7 femto cell DL: Max.Data rate and DL:Max.Throughput for all sites antenna 1

The designed network maximum data rate is found between the theoretical and calculated data rate.this results shows us the simulated throughput and data rate is accurate for desired femto cell network planning.

FIGURE 5.41: Femto cell DL:Max.Data rate and DL:Max.Throughput for all sites antenna 1

5.4 Performance Evaluation of Planned Pico cell Network

5.4.1 Pico cell Site 1 antenna 1 performance analysis for designed network

5.4.1.1 Pico cell Site 1 antenna 1 Coverage Prediction by power level

A femto cell coverage prediction with power level that shows in figure 5.5 contains less transmitted power us compared to pico cell coverage prediction. This tells us the prediction of femto cell had been the best signal strength for all sites within Omni directional antenna. femto cell signal prediction result have acceptable coverage as compared to pico cell as we observe from the simulation result in figure 5.5 and figure 42 .

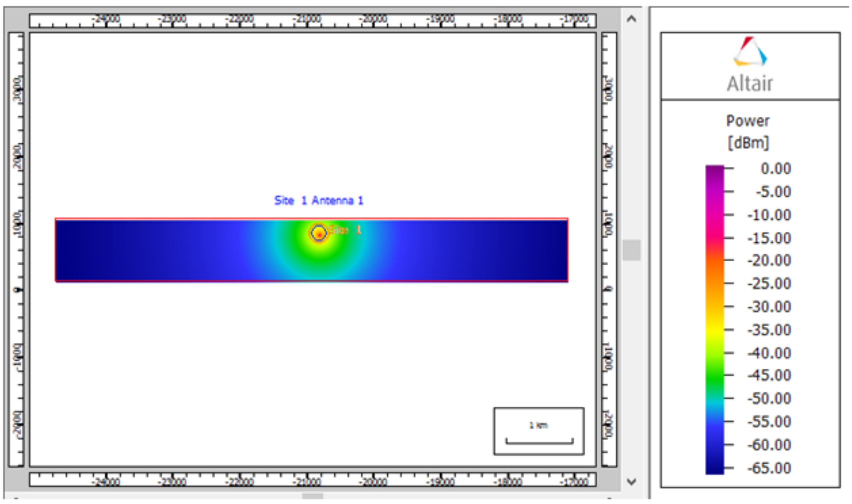


FIGURE 5.42: pico cell Coverage Prediction by power level .

5.4.1.2 Comulative Probability of pico cell Coverage area with power level

The cumulative probability analysis result of femto cell and pico cell shows comparison of coverage area versus best signal strength value. The analysis result shown in figure 5.6 and 5.43 the site1 antenna1 area are covered by strong power level and its power values range from negative 60dBm to 0 dBm for femto cell.But the pico cell power level covered from negative 60dBm to 100dBm this needed a high power to get best signal quality as compared to femto cell and also other areas are covered by acceptable power level when we compare our design receiver sensitivity signal level to - 100dBm.

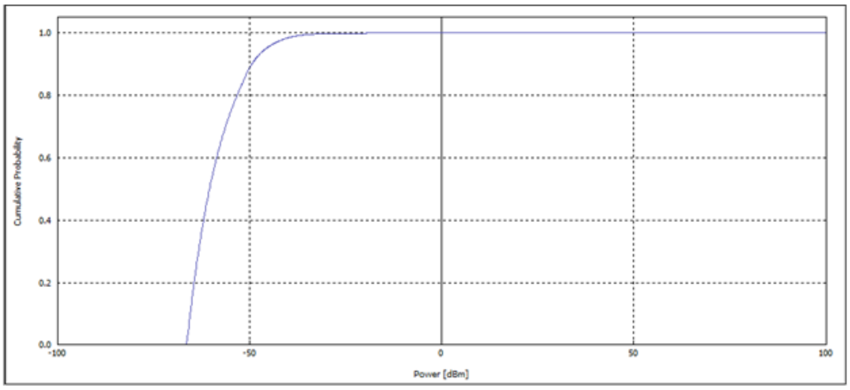


FIGURE 5.43: pico cell Coverage area with cumulative Probablity Vs power..

5.4.1.3 Pico cell coverage area with path loss

The simulation result in figure 5.8 and 5.44 below justifies femto cell and pico cell path loss value respectively.That shows fem to cell path loss had been the minimum path loss as compared to pico cell path loss at our designed cell radius.

Hence we can get an acceptable signal level which is better than our receiver sensitivity signal level in femto cell, it implies the signal can fully serve a user at this particular point. And the cumulative probability is shown in figure 5.9 and 5.45 for femto cell and pico cell respectively.

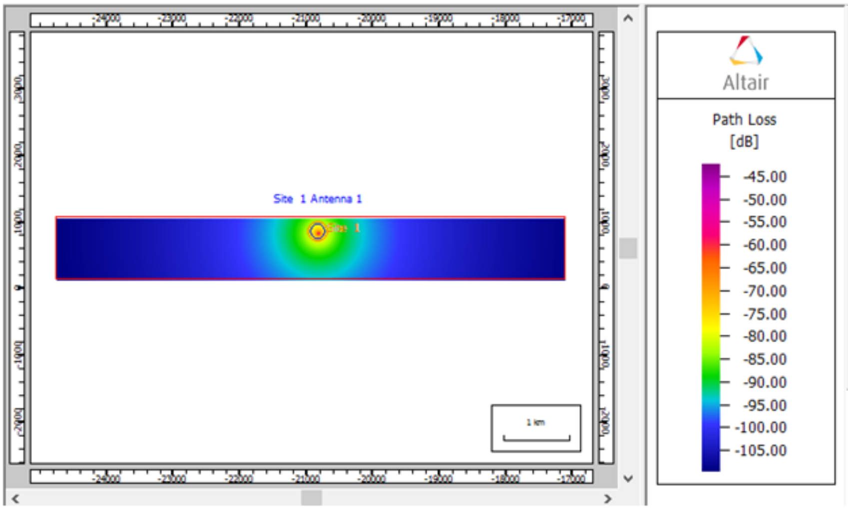


FIGURE 5.44: pico cell Site1 antenna 1 path loss.

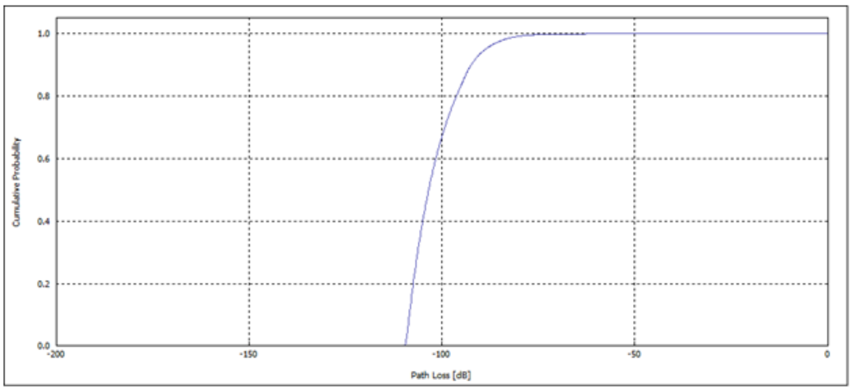


FIGURE 5.45: pico cell site 1 antenna 1 cumulative Probablity Vs path loss. .

5.4.1.4 Field strength of pico cell for site 1 antenna 1

Femto cell and pico cell coverage prediction by field strength level shown in figure 5.11 and 5.46 respectively shows the prediction of the best signal strength with the minimum field strength at each pixel within the computation site. This signal prediction simulation result are acceptable, value for femto cell as compared to pico cell when we see result in its legend.

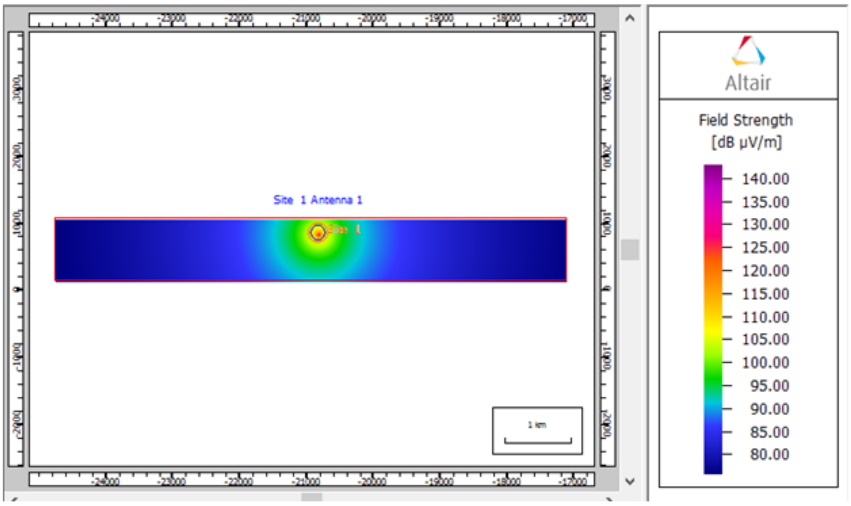


FIGURE 5.46: field strength of pico cell .

5.4.1.5 Cumulative Probability pico cell coverage with field strength

Pico cell cummulative probability coverage shows that most areas within the computation sites are covered by strong signal level and its signal values ranges high as compared to femto cell. But the areas are covered by acceptable signal value when we see our design receiver sensitivity signal level.Hence femto cell is acceptable.

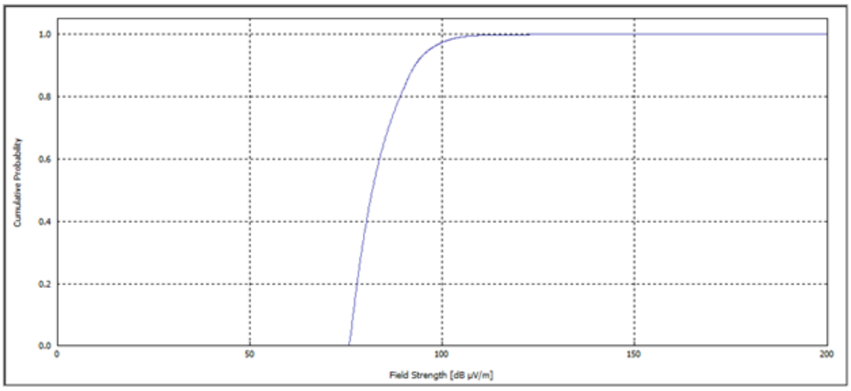


FIGURE 5.47: pico cell cumulative probability Vs field Strength.

5.4.2 Pico cell network received power for site 1 antenna 1

Figure 5.32 and 5.48 shows femto cell and pico cell received power profile view of point analysis between a reference transmitter and receiver respectively. The simulation signals level of the received signal from the selected all Sites femto cell antenna 1, transmitter is greater than our designed receiver sensitivity signal within 17m and pico cell site 1 antenna 1 transmitter designed with in 17.68m cell radius. Hence the pico cell QOS is less than femto cell QOS.Because pico cell needed high power compared to femto cell to get high signal quality.

5.4.3 pico cell network cumulative probability Vs received power

The cumulative probability of pico cell designed network shows the received power of the designed network performance.

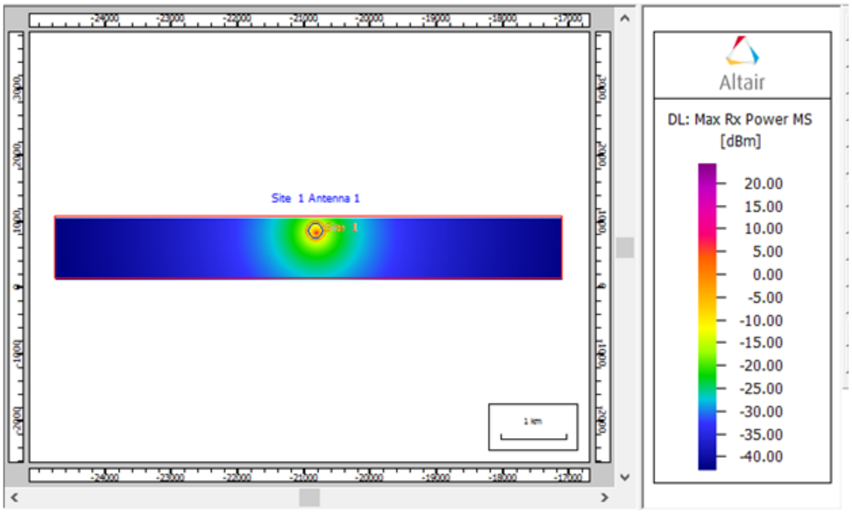


FIGURE 5.48: pico network received power for site 1 antenna 1

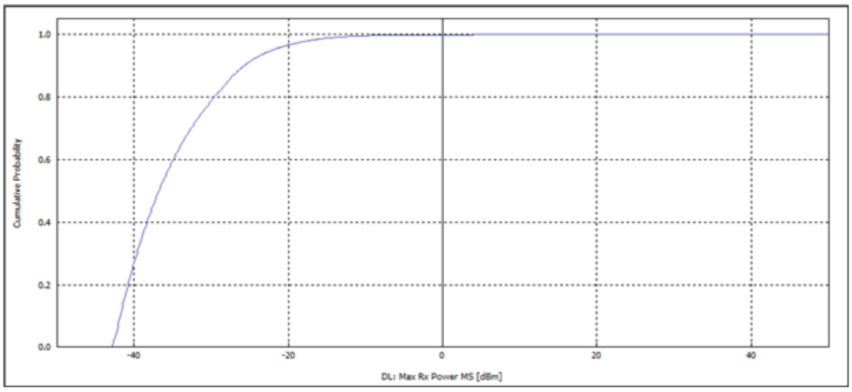
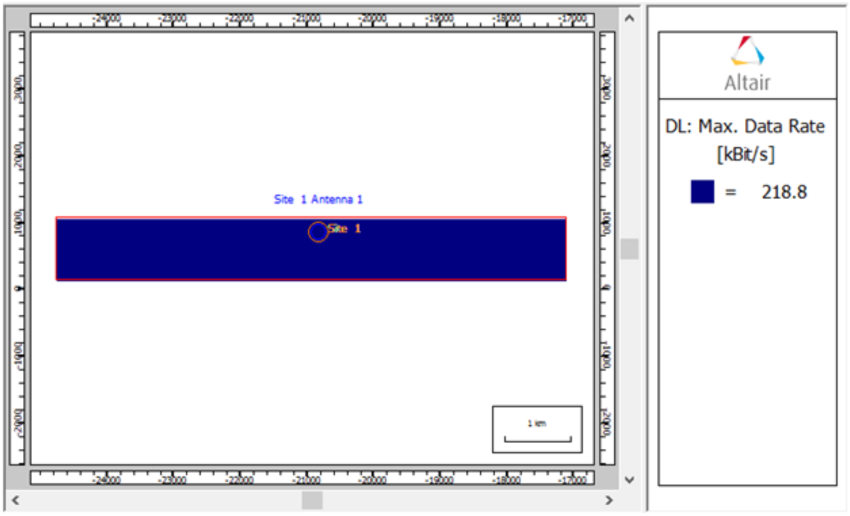


FIGURE 5.49: femto cell network cumulative probability Vs. received power for all sites antenna1.

5.4.4 Pico cell DL: Max.Data rate and DL:Max.Throughput for site 1 antenna 1

The pico cell designed network maximum data rate is less than femto cell designed network.Hence femto cell simulated throughput and data rate is accurate as compared to pico cell data rate for desired network planning.



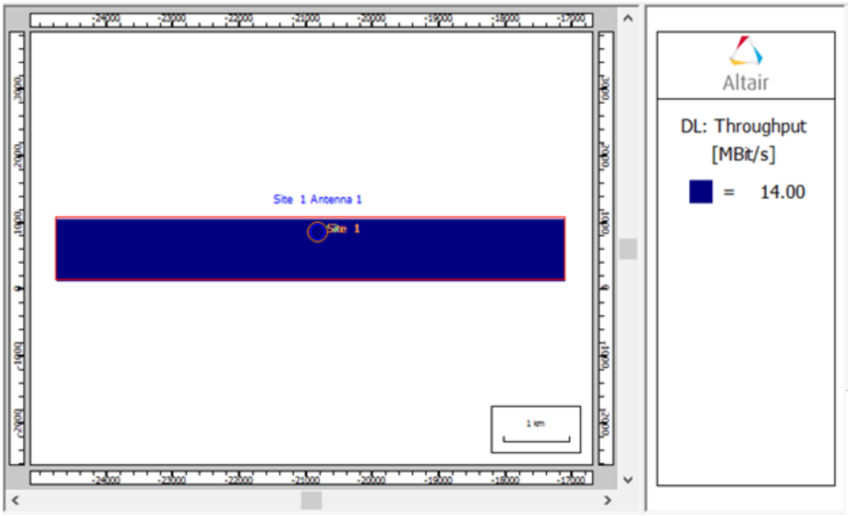


FIGURE 5.50: Pico cell DL:Max.Data rate and DL:Max.Throughput for site 1 antenna 1

Chapter 6

Conclusion and Recommendation

6.1 Conclusions

Indoor radio network planning in wireless communication networks had been studying and planning considerations in small cell coverage and capacity for Pico cell and femto cell LTE networks had been describing in detail more focused in fem to cell LTE networks due to the best technology as compared to pico cell with the improvement of 12.23%.With 1800 MHz frequency spectrum, small cell indoor radio network planning in wireless communication networks is very important in provision of sufficient coverage, sufficient network capacity and good network quality.

An indoor radio network plan for a selected building sites with Auto cad database was successfully produced using win Prop Radio Planning Software – Tool.Analysis of simulation models were performed by matlab software tool.Where us Prediction results based on coverage by signal level, received power, SNIR and coverage by path loss level were obtained using the indoor radio planning software (winProp).

6.2 Recommendations

We would like to improve the indoor radio networks performance by using small cell solutions.Hence the main solution for this network improvement is deploy small cells in detail. To design the radio network in detail we would take the desired area to get accurate network quality deployment.This will be the future work for this thesis.

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Chapter 7

Appendix
Matlab code for indoor radio network modeling simulation

Matlab code

```
clear all; clc
d1meter=4:1:200
x=(d1meter);
c=3*1e8;
fcc=1800*10^6;lamda=c/(fcc*1e6);
Lc=1.26;n= 1:1.4,1:2
Lmf=n*(20*log10((4*pi)*d1meter/lamda))+Lc;
Lfreespace=20*log(4*pi*d1meter/lamda);
kw=3,Lw=3.16,Lc=1.26
Lmk=Lfreespace+Lc+kw*Lw;
Lmk=20*log(4*pi*d1meter/lamda)+10*log10(Lc+kw*Lw);
kw1=1,kw2=2,kf=12
Lw1=2.19,Lw2=4.9,Lf=67.6
b=0.46
Lc=1.26
```

```
Lmw=Lfreespace+Lc+(kw1*Lw1+kw2*Lw2+ kf*Lf);
Lmw=20*log10(4*pi*d1meter/lamda)+10*log10(+Lc+[kw1*Lw1+kw2*Lw2+kf*Lf]);
N=28;
pf(n)=12;
ITULindoor=20*log10(fcc)+N*log10(d1meter)+pf(n)-28
figure(1)
hold on
plot(x,Lmf,'r-s');
hold on
plot(x,Lmk,'k--');
hold on
plot(x,Lmw,'g-.');
hold on
plot(x,ITULindoor,'k-o');
xlabel('Distance(m) ');
ylabel('Path loss (dB)')
legend('Modified freespaceLoss','Motley-keenan','Cost-Multi wall','ITULindoor')
```