Addis Ababa University

Addis Ababa Institute of Technology

(AAiT)

School of Electrical and Computer Engineering

UMTS/WCDMA Coverage and Capacity Planning for Better Safety and Operation of Railway, A Case Study of Addis Ababa – Djibouti Route

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A Thesis Submitted to the School of Electrical and Computer Engineering at Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Sciences in Electrical Engineering for Railway Systems

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Addis Ababa, Ethiopia

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Declaration

I, the undersigned, declare that this thesis is my original work for the fulfillment of MSc. degree in Electrical Engineering for Railway Systems has not been submitted for a degree in this or any other universities and all sources of materials used for the thesis have been fully acknowledged.

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I certified that the above statement made by the student is correct to the best of my knowledge and has been submitted for examination with my approval as university advisor.

Name: Dr. **Yalemzewd Negash**

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Abstract

This thesis involves planning of coverage and estimated capacity of Universal Mobile Telecommunications Service network for railway (UMTS-R) which uses Wideband Code Division Multiple Access (WCDMA) radio interface between the third generation (3G) base station and user equipment for railway better operation and safety by replacing Global System for Mobile Communication – Railway (GSM-R) to ensure safety and increase additional services for future railway system so that customer satisfaction is enhanced.

The Addis Ababa – Djibouti railway route at long stage operation (in 2035) is taken as a case study and geographical and morphological nature of the route is taken with the assumption of further extension of suburban areas in the future. The design involves certain steps including: creating route path on Google earth as KML/KMZ file, convert to AutoCAD file using Zonums online solution and then to TAB file using MapInfo professional 7.8. Finally Atoll radio network simulation uses this file as an input to design the coverage while nature of each node B site is taken in to consideration to optimize the coverage and capacity.

The design involves numerous parameter calculations and WCDMA standard or assumed values used to compute the link budget of two samples that are mostly used data rates (12.2Kbps voice and 144 Kbps packet switched data) by using Okumura-Hata path loss model which is chosen reasonably after simulating the cell range versus path loss using MATLAB software.

A rough estimation of both uplink and downlink maximum capacity is done for the mixed traffic. Repeated simulation trials have been done to obtain better redundant or reliable network service and ends up with 97 Node B sites to serve a redundant system in which half number of the total Node Bs can fully operate the route with acceptable signal level for the case study route.

Finally, a rough comparison of Universal Mobile Telecommunication Services – Railway (UMTS-R) and GSM-R capacity and coverage for the route is done. As a result, an extra estimated capacity and better and reliable coverage is obtained. To make this design full and practically operable, there is a room to extend on analysis of inters and intra system interference, Electromagnetic Compatibility analysis, cost analysis and detail system optimization.

Key words: *GSM-R, WCDMA, UMTS-R, Optimization, Capacity, Coverage, ATOLL, EMC*

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List of Abbreviation and Acronyms

2G	Second generations
3G	Third Generations
3GPP	Third Generation Partnership Project
α	Orthogonal-ity Factor
AA	Addis Ababa
AAiT	Addis-Ababa Institute of Technology
ATC	Automatic Train Control
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
BS	Base Station
dB	Decibel
dBm	Decibel-Miliwatt
C/I	Channel to Interference ratio
CN	Core Network
CS	Circuit Switched
E	Erlang
EiRENE	European Integrated Railway Radio Enhanced Network
EMC	Electro-Magnetic Compatibility
ESG	Engineering Service Group
ERC	Ethiopian Railway Corporation
ETSI	European Telecommunication Standard Institute
EU	European Union
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FIT	Failure In Time
GHz	Giga Hertz
GoS	Grade of Service
GPS	Global Positioning System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication

GSM-R	Global System for Mobile Communication –Railway
HCR	High Capacity long Range
hr	Hour
Hz	Hertz
HSDPA	High Speed Downlink Packet Access
IMT	International Mobile Telecommunications
IP	Internet Protocol
ITU	International Telecommunication Union
Kbps	Kilo bits per second
KHz	Kilo Hertz
KRTCS	Korea Radio Based Train Control System
Km	Kilo Meter
Km^2	Square Kilo Meter
LCR	Low Capacity Range
LTE	Long Term Evolution
m	Meter
Mbps	Mega Bits per Second
Mbyte	Mega Byte
MHz	Mega Hertz
MRSL	Minimum Received Signal Level
MS	Mobile Station
MSc.	Master of Science
MSC	Mobile Switching Center
MTBF	Mean Time between Failures
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
MUD	Multi User Detection
NB	Node B
OTA	Over The Air
PDF	Probability of Dangerous Failure

PICH	Paging Indication Channel
PN	Pseudo Noise
PS	Packet Switched
PSF	Probability of Safe Failure
QoS	Quality of Service
R	Radius
RBS	Radio Base Station
RNC	Radio Network Controller
RRM	Radio Resource Management
SCADA	Supervisory Control and Data Acquisition
SF	Spreading Factor
SMS	Short Messaging Service
SUI	Stanford University Interim
TD-CDMA	Time Division – Code Division Multiple Access
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division –Synchronous Code Division Multiple Access
TRX	Transmitter Receiver
UE	User Equipment
UMTS	Universal Mobile Telecommunications Service
UPS	Uninterrupted Power Supply
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access
WiBro	Wireless Broadband
WiMax	Worldwide Interoperability for Microwave Access

Chapter One

1. Introduction

1.1 General Background

Nowadays, railway transport system becomes an indication for the economy level of a country since it is an important infrastructure acting as a backbone of traffic. The modern rail transport is characterized by many factors including: Safe Operation, large transport capacity (volume of cargo or passenger), environmentally friendly (uses electric traction) [1].

Railway transport has been growing from the early stage. Advancements in technology (automation, control, protection and operation) of railway transport is growing from time to time and value added services are becoming one criteria of railway transport. Those advancements continue to contribute on economical, political, social and environmental impacts.

Railway safe operation is ensured mainly by designing a safe signaling system in addition to other supportive actions. Railway signaling is a system used to safely direct railway traffic in order to prevent trains from colliding [1]. This system provides enough information to moving trains, working stuffs and control rooms to overcome the susceptibility to collision of trains due to the weight of trains and momentum.

The signaling terms have been developing from time to time. The first signaling system was manual operating by a signal man showing different aspects based on the occupancy of the track. Colored flags and lights were used during day and night respectively. It works based on time and there was no system to track train location [2]. The advancement of railway signaling come up with the introduction of fixed signals which are essentially wooden boards mounted on rotating posts. Meanwhile, it grew in to a fixed and moving block signaling options controlled by cables or/and wireless network. Moreover, the advancement helps to integrate it with many other operations like automatic train protection (ATP), automatic train control (ATC) and automatic train supervision (ATS). Hence, the advancement of technology forces to change the railway safety level from time to time and is expected to grow as soon as new technology emerges.

Currently GSM-R is the dominant network planning and capacity coverage system for protection almost all over the globe. It is described as a safe network service up to speed of 500Km/hr [3].

This change of protection comes true due to advancements in technology and increase in people's interest. People's interest doesn't have limit and further advancement is required. Moreover, advancements are required because better safety is the primary factor in railway transport.

The mobile communication industry is currently shifting its focus from second generation (2G) towards the third generation (3G) and fourth generation (LTE). The shift is not only related to the evolution of the (radio) access technology, but also to the vision of the development of service provisioning and demands, customer expectations and customer differentiation [4].

1.2 Problem Statement

The advancement of technology changes the way peoples live and is trying to fulfill the unlimited human interest. Moreover, in railway safety is the primary factor in which the large volume of passengers and freight should destined safely. The mobile operators are upgrading their network from Global System for Mobile communication (GSM) in to higher generations like Universal Mobile Telecommunication Service (UMTS) and long Term Evolution (LTE) to fulfill the customer's satisfaction and ensure quality of service (QoS). Hence, the advancement of wireless technology should also be applied to railway transportation system which safety is its primary factor. Scholars (mentioned in the literature review) put indications as GSM-R will be phased out before 2025 [5]. So it is expected that WCDMA and LTE will control the task of GSM-R in the future. In addition to this, technology advancement is supporting high network generations with reducing the equipments cost. Hence, the capacity and coverage design trial should be done before the estimated phase out time of GSM-R.

In case of Ethiopia and Djibouti, the Addis Ababa – Djibouti route is the most critical route for the economy of the countries. So a reliable, efficient, safe, comfortable train operation is necessary both for the people and for the economy of the countries, especially for Ethiopia a land locked country. Moreover, as the country has a fast growing economy, the amount of trains, freight, passengers and their need will increase on the upcoming years. As a result the data communication across the route will increase and network availability and coverage is expected to increase so that safety will be ensured.

This thesis aims to design the coverage and capacity estimation of railway line using UMTS/WCDMA which has higher capacity is chosen as a key candidate for the next railway operation due to its improvements regarding to spectral efficiency, handover and security. Hence, implementing UMTS/WCDMA technology trial is a solution for better operation of next railway systems. It will provide increased data rate, safe signaling, additional automated operations and other value added services that satisfy customers like providing entertainment as the route has longer travel time.

1.3 Thesis Objective

1.3.1 General Objective

The general objective of this thesis is a universal mobile telecommunications service for railway (UMTS-R) system design that is efficient, reliable and safe network coverage with estimated maximum capacity and optimization based on WCDMA radio technology for better operation of the railway system, taking Addis Ababa – Djibouti route as a case study. After the completion of the thesis a better safety level and capacity will be maintained in addition to better customer satisfaction with optimized cost. Hence, the main objective is to improve safety and service as the line capacity and value added services are increased.

1.3.2 Specific Objective

The specific objective of this thesis is the investigation of the detail works during the design of coverage and capacity using UMTS technology for railway. Hence, it includes:

- Investigate the techniques of upgrading coverage and capacity for railway with UMTS
- Compare the designed capacity and coverage with the existing technology (GSM-R).
- Compare, evaluate and choose the radio propagation models
- Involve and understand the difficulty of WCDMA capacity and coverage planning
- Introducing the generation with the next network technology of railway, knowledge of design and pave a way for others to proceed through.
- Consideration of system redundancy

1.4 Literature Review

Several works has been done for the coverage and capacity planning of UMTS/WCDMA technology for cellular communication. Eventhough, non of them are discussed for railway, indirectly some of the studies recommend as UMTS and LTE will be the next railway system technologies.

Every WCDMA radio network planning uses almost the same procedures. The difference among designs arises from frequency range selection, area type (Urban, Suburban or Rural), network capacity, area coverage, type of service the network provides, behavioral nature and estimated number subscribers of the network under design and next extension probability of the system in addition to other system specific parameters. WCDMA radio network planning includes: dimensioning (initial planning), detail capacity and coverage planning and network optimization [6]. The WCDMA dimensioning phase ends up with approximate number of base station sites, base stations and their configurations and other network elements estimation, based on the operator's requirements and the radio propagation in the area is explained theoretically [6].

In UMTS/WCDMA radio network planning, coverage and capacity can't be considered independently unlike GSM but should be planned at the same time with proper guidelines [4]. This is an indication to the difficulty of WCDMA radio network design which creates a tradeoff between coverage and capacity of a single network. This tradeoff relation is called cell breathing effect. The difficulty of WCDMA network can be reduced by applying some optimization techniques [4].

Deployment of repeaters in heterogeneous multiservice networked environment (especially urban area) of WCDMA network enhances the quality signal of the system [7]. Moreover, the area coverage across urban is small with high capacity whereas in rural, high large coverage distance with relatively small capacity is considered in radio network design [7]. This shows the density of radio network access points are different regarding to environment type.

In case of railway radio network design, the existing highly reliable radio access system Global System for Mobile communication – Railway (GSM-R) network design is evaluated by many scholars. GSM-R can operate to fast moving trains up to 500 Km/hr [3]. Its principle of frequency channel distribution between cells and frequency channel reuse are discussed in [3, 8].

Study of international commission of railway mentioned that, even though GSM-R is the highly deployed current wireless network access system for railway safety, the new technologies will replace GSM-R and will no more operable after 2025 in European Union (EU) [5]. This investigation of new technology for railway has been started since 2010 and was expected to take 10 years (5 years to migrate to the successor and 5 years to define specification, deployment and legal position) to implement the next generation (third generation (UMTS/WCDMA) and long term evolution(LTE)) possible radio access technique [5].

European Train Control System (ETCS) proposed for the next railway operation to be safe, efficient, reliable, less costly, and improved performance with updated technology mainly for the signaling system [7]. It is proposed to avoid the need of traditional traffic light and speed signals mounted alongside the route track. Instead trains will be equipped with in cab signaling which informs the driver, the allowable speed and movement of trains [9]. The figured out signaling system transition from fixed block signaling in to wireless moving block signaling as shown in figure 1-1 below.

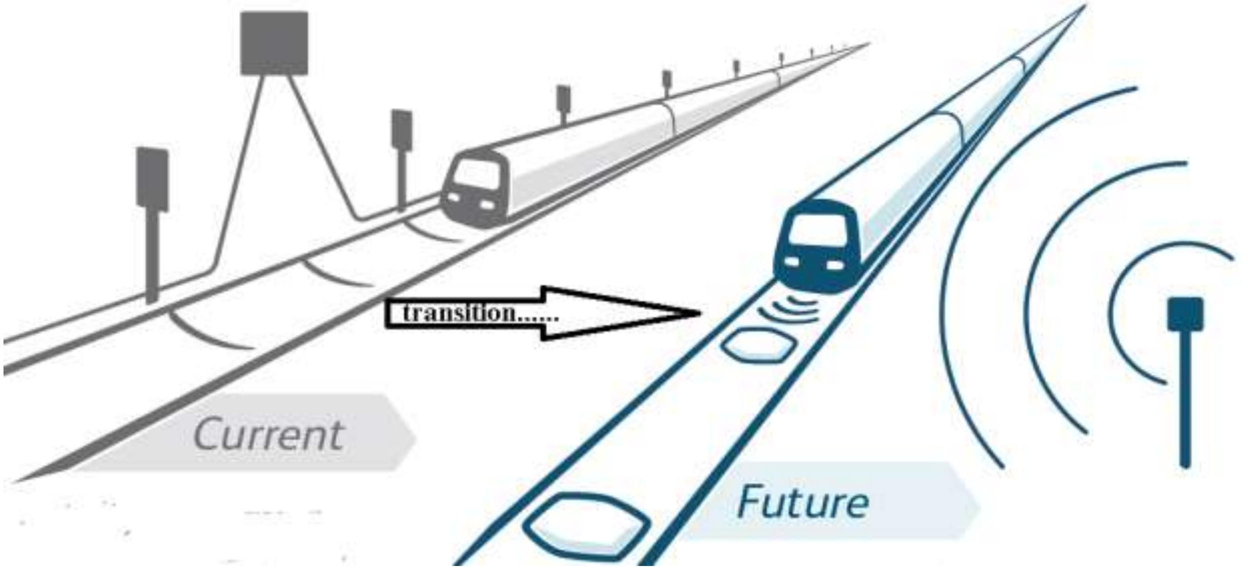


Figure 1-1: Estimated future European signaling system [9]

Even though, transition of radio access system to higher generation technologies is very necessary and mandatory as the route capacity increases and to enhance service types across the route so that customers satisfaction increases, its difficulty of design is and optimizing the design to reduce cost is a challenge of every network engineer [9]. Calculation methods for capacity analysis in WCDMA systems by hand-calculator and/or by personal computer are needed for mobile cellular engineers for preliminary design purposes, and/or for quick evaluation purposes [10].

For the cases study (Addis Ababa – Djibouti) railway rout on its long stage operation (2035), a GSM-R design is made [3] with no assumption of increased customer satisfaction and line capacity beyond the primary expectation of the Chinese design. It is sufficient for the all the services other than large capacity information and additional real time and non real time services with less than 8 Mbps calculated total line capacity. A real geographical and morphological nature of the route from Google earth is used to locate the position of base stations (BSs) with their two sector configuration. The thesis [3] ends up with 37 BSs for the whole route with no redundancy (only a single operable network system).

This thesis follows all necessary steps and ideas of the acknowledged references to create a footprint on designing Universal Mobile Telecommunication Systems for railway (UMTS-R) using WCDMA radio access technology to fulfill the future increased human interest and capacity. Moreover, a redundancy is primarily considered to increase availability of the designed network so that safety is ensured. This thesis uses Google earth data to create the route (Addis Ababa – Djibouti) and design of redundant node B (NB) is done while real geographical nature of the route is considered to optimize the capacity and coverage.

1.5 Scope of Thesis

The scope of this thesis includes introducing the UMTS/WCDMA system, choice of propagation model for the case study frequency (850Mhz), choice of the handoff mechanism, rough estimation of maximum uplink and downlink capacity, analyzing the geographical nature of the route, dimensioning (link budget calculation), designing a detail radio coverage with optimizing based on the nature of the site where transmitter is to be deployed, analyzing the result and comparison of the result with the GSM-R system design of the case study. This thesis mainly concerns with the coverage of the route with a redundant system to ensure reliability.

1.6 Thesis Outline

This thesis consists six chapters. The chapter's content can be summarized as follows.

Chapter One: this chapter introduces the background of the system growth, the problem statement, objective and scope of the thesis, some literatures and the methodology followed on this thesis.

Chapter Two: deals with reviewing the proposed technology UMTS/WCDMA. It defines the UMTS operating modes, the architecture of WCDMA, the improvements, UMTS-R services and reasonable choice of the UMTS frequency band for the case study. Finally, traffic intensity estimation is computed.

Chapter Three: the main concern in this chapter is the overview of the case study route. This describes the design considerations of the route, the number of estimated crew on the long stage operation (2035), the type of track and signaling control system proposed, topographical and geographical nature of the route and estimation of peak hour train capacity in the long stage.

Chapter Four: this chapter is a core chapter that explains the UMTS-R capacity and coverage design process in detail. It involves the dimensioning, link budget calculation for the case study, radio propagation model selection, area coverage calculation for different environmental natures and system design with redundancy.

Chapter Five: the final simulation task with its result is organized in this chapter. It includes the simulation process using Atoll simulation software and intermediate software, the result of the design, the coordinate location of each Node B in Google earth, estimated capacity of the route, comparing the result with GSM-R result, coverage evaluation and analysis of the result.

Chapter Six: this is the last chapter preceding the reference and appendix part which discuss on the limitation and conclusion of the thesis. Finally, it mentions the ways that this thesis can be extended further to make it more reliable and applicable.

1.7 Methodology

The thesis work is conducted as a case study based on the published technical papers mentioned in (section 1.4) and others obtained from academic scholars who conducted UMTS/WCDMA for public cellular network. The procedure is almost the same, except the type and scope of the service is limited. The work flow of this thesis can be summarized in figure 1-2. It generally evolves reviewing related works followed by initial and detail planning, testing and checking. The detail methodology of this work is discussed in chapter four for the case study.

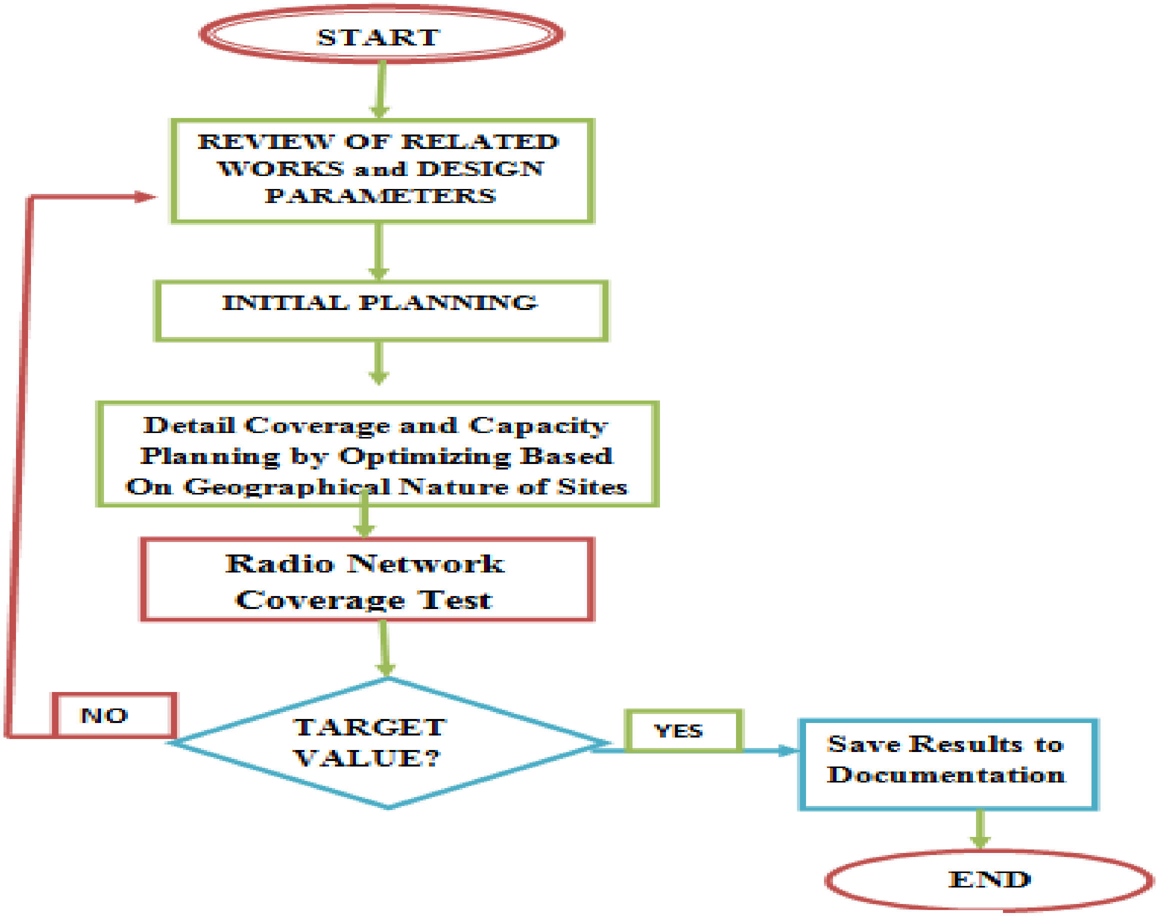


Figure 1-2: Work Flow Chart

Chapter Two

2. UMTS/WCDMA Review

2.1 Universal Mobile Telecommunication System (UMTS)

UMTS is a third generation mobile cellular system for networks evolved from the GSM standard. It is developed and maintained by the 3GPP (3rd Generation Partnership Project) which is a component of the International Telecommunications Union IMT – 2000 standard set.

UMTS uses wideband code division multiple access (WCDMA) as a media access technique and uses a 5MHz channel space unlike GSM channels spaced with 200 KHz. Even though, the UMTS signal bandwidth is considered as 5MHz, 0.58MHz in either side of the channel is a guard band. Hence, excluding the two guard bands in either side will yield a channel bandwidth of 3.84MHz.

2.1.1 UMTS Frequency Bands

UMTS consists of two complementing UMTS Terrestrial Radio Access (UTRA) radio options; Frequency Division Duplex (FDD) and Time Division Duplex (TDD). FDD is applied for paired bands and large area coverage, whereas, TDD is applied for asymmetrical applications and hot spot. UMTS – FDD uses the WCDMA radio access technology whereas, UMTS-TDD uses Time Division – Code Division Multiple Access TD-CDMA) or Time Division –Synchronous Code Division Multiple Access (TD-SCDMA) for High Capacity Rate (HCR) and Low Capacity Rate (LCR) mode respectively. FDD uses large frequency spectrum, though, generally at least twice the spectrum needed by TDD. In addition, there must be adequate spectrum separation between transmit and receive channels.

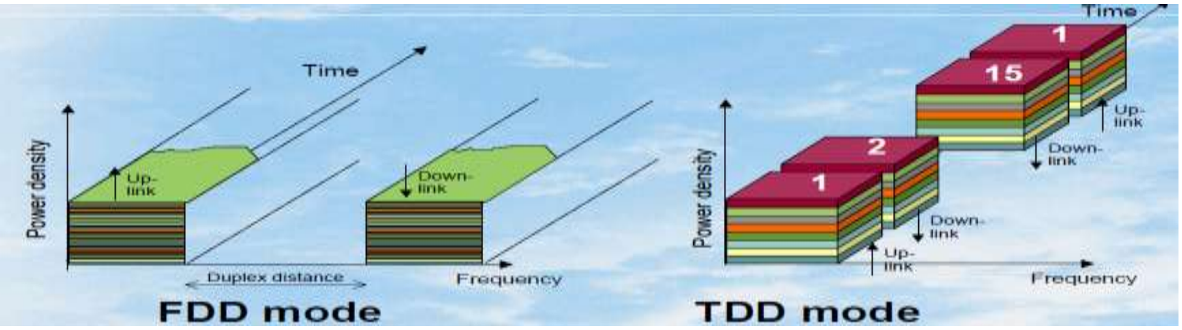


Figure 2-1: UMTS/UTRA operating modes [11]

For macro cell UMTS – FDD mode, the range of the cell is **350m** up to **20km**, which is mainly applied in suburban/rural, high speed mobility and a reliable achievable data rate of **144kbps** but rarely up to **344kbps** at high speed. This case study will take the UMTS-FDD mode.

The reliable voice and data communication is made via the wireless path called channels. UMTS channels to be used in the system are divided in to three based on the contribution and type of data they support.

Logical Channels: - determines what type of data to be transferred.

Transport channels: - determines how and with which type of characteristic the data is transferred by the physical layer. They contain the data generated at higher layers, which is carried over the air and are mapped over the physical layer to different physical channels. The data is sent by transport block from MAC layer to physical layer and generated by MAC layer every 10ms [11].

There are two types of transport channels: dedicated and common channels. The dedicated channel is reserved for a single user only supporting soft handover and fast power control. Whereas, the common channel can be used by any user at any time which sometimes support fast power control and don’t support soft handover.

Physical channels: The physical channels carry the payload data and govern the physical characteristics of the signal.

The three UMTS channels by themselves have various types of channels used for different types of services either on the uplink (UL) and/or downlink (DL) path. Studying each channel is a broad task and is beyond the scope of the thesis because the main task here is capacity and coverage planning. It is tabulated and summarized in [12].

2.1.2 UMTS Architecture

The UMTS radio network has three main sub systems; Core Network sub system, Access Network (AN) sub system and Mobile Station (MS) sub system.

UMTS uses a WCDMA as radio access technique as air interface technology. Hence, the architecture of WCDMA system directly explains the architecture of UMTS as shown in figure 2-2 below.

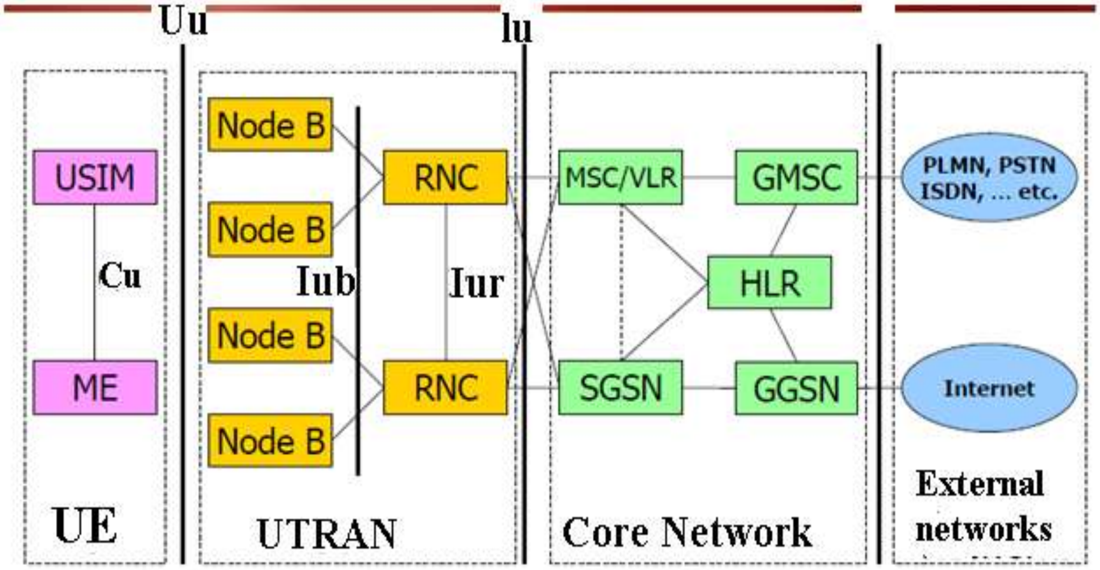


Figure 2-2: Network elements of WCDMA public land mobile Network [13]

2.2 Wide band Code Division Multiple Access (WCDMA)

WCDMA is a radio access technique based on CDMA technology used in UMTS (3G) system. This thesis aims to replace the task of GSM-R with UMTS/WCDMA for better operation. Hence, comparing some parameters of GSM and WCDMA is provided in (table 2-1) below.

Table 2-1: Comparison of WCDMA and GSM in some parameters [14]

Parameter	WCDMA	GSM
Carrier spacing	5 MHz	200 kHz
Frequency reuse factor	1	1-18
Power control frequency	1 .5 KHz	<= 2 Hz
Quality control	Radio Resource Management algorithm	Network planning (frequency planning)
Frequency diversity	Multipath diversity with RAKE receiver	Frequency hopping
Packet data	Load based packet scheduling	Time slot based scheduling with GPRS
DL transmit diversity	Supported for improving downlink capacity	Can be applied but not supported by standard

2.2.1 WCDMA Network Elements

To provide a reliable radio access interface, the WCDMA radio access mechanism has four main sub systems; UE, UTRAN, core network and external networks as shown in figure (2-2).

2.2.1.1 Core Network (CN)

It is a central part of the massive communication system that mainly provides services to target subscribers. It has many data bases and parts including:

Mobile Switching Center (MSC): - is a subsystem that is mostly associated with switching functions such as call set up, call release and routing.

Gateway Mobile Switching Center (GMSC): - is a special kind of MSC that is used to route calls outside the mobile network.

Visitor Location Register (VLR): - is a data base associated to MSC, which contains the exact location of UE which is currently served by the MSC.

Home Location Register (HLR): - is the main data base of permanent subscriber information for the radio network.

Serving GPRS Support Node (SGSN): - is a main component of the GPRS network, which handles all packet switched data within the network, e.g. the mobility management and authentication of the users.

Gateway GPRS Support Node (GGSN): - is a main component of the GPRS which is responsible for the interworking between the GPRS network and external packet switched networks like internet and X 25 networks.

In this thesis dimensioning of the core network is not considered and is out of scope. Only capacity dimensioning of UTRAN is considered along with coverage planning at the Uu interface.

2.2.1.2 UMTS Terrestrial Radio Access Network (UTRAN)

UTRAN is a collective term for the network and equipment that connects mobile handsets to the public telephone network or the Internet. It contains Node B's and Radio Network Controllers (RNC's) which make up the UMTS radio access network [15]. This 3G communication network can carry many traffic types which includes real time circuit switched up to IP based packet switched. The main aim of UTRAN is to create connectivity between user equipment and core network as depicted in figure 2-3.

Radio Network Controller (RNC): - Provides control functionality to one or more node B (NB). There is a logical connectivity interface between RNC and Node B called **lub**, due the fact that they should not separate physically. The RNC also owns radio recourses.

Radio Network Subsystem (RNS): - is a collective name to RNC and Node B. a single UTRAN can have more than one RNS.

UTRAN Interfaces: - the UTRAN subsystems are connected either internally or externally to other entities via interfaces.

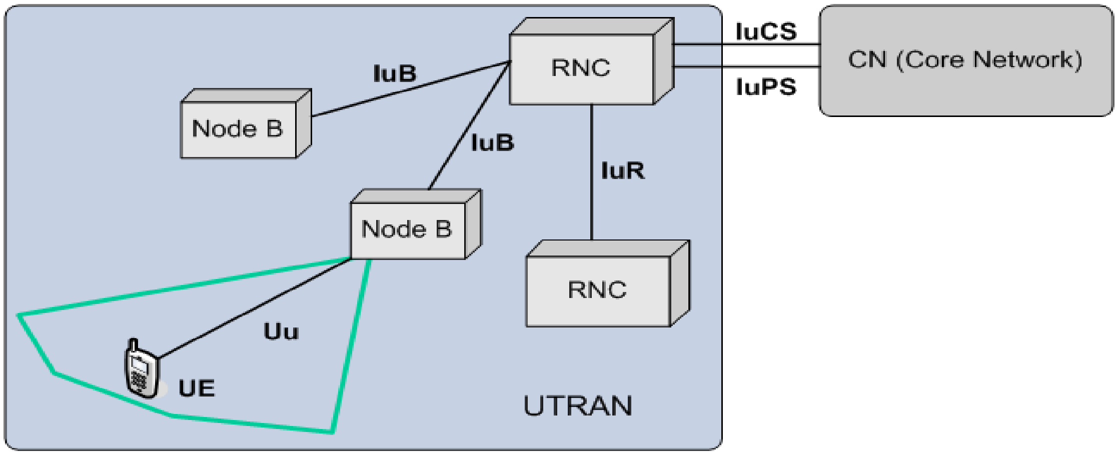


Figure 2-3: UTRAN Architecture [16]

Iu interface:- an external interface that connects the RNC to the Core Network (CN). It interfaces to both circuit switched core network (luCS) and packet switched core network (luPS).

Uu interface: - is also an external interface, connecting the Node B with the UE.

Iub interface: - is an internal interface connecting the RNC with the Node B.

Iur interface: - is most of the time internal interface that connects two RNCs with each other.

2.2.1.3 User Equipment (UE)

This subsystem is the terminal subsystem which directly refers to the service accessory. This has two main parts.

Mobile Equipment (ME): is the radio terminal used for radio communication over the Uu interface. For the case study, cab radio, devices (end terminals) that keep in communication with the node B found at control rooms, inside the train, stations, handsets and dispatching are called mobile equipments (ME's).

UMTS Subscriber Identification Module (USIM): is a smart card that holds the subscriber identity, performs authentication algorithms, and stores authentication and encryption keys and some subscription information that is needed at the terminal. Some WCDMA physical layer parameters are listed in table (2-2).

Table 2-2: WCDMA physical layer parameters [11]

Parameter	Magnitude
Carrier Spacing	5MHz
Chip Rate	3.84Mcps
Uplink SF	4 to 256
No. of chips/slot	10ms (38400 chips)
No. of slots/frame	15
Downlink SF	4 to 512
Channel Rate	7.5 Kbps to 960 Kbps

Paging Indication Channel (PICH) Frame Structure: is a downlink WCDMA physical channel, in which its single radio frame structure lasts 10ms which have 15 slots each 2/3ms [11].

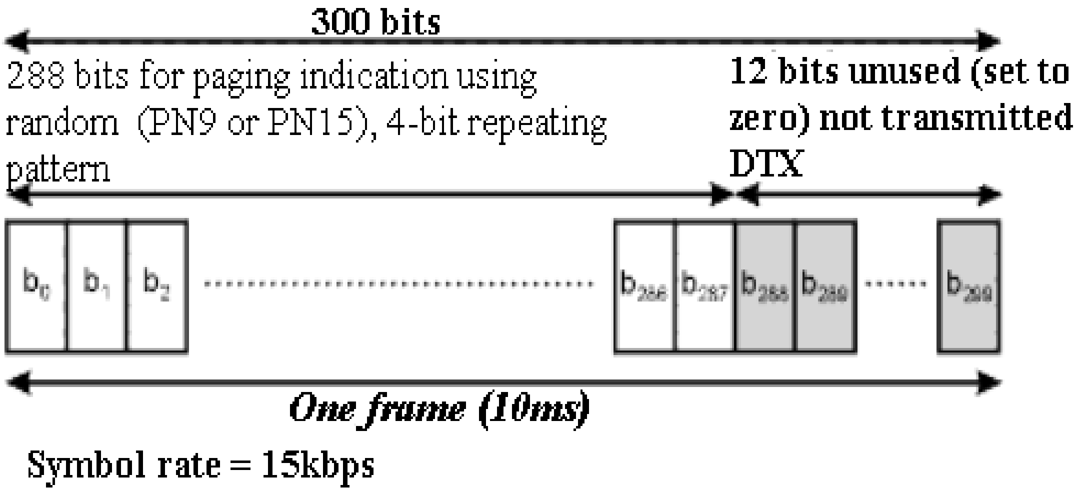


Figure 2-4: PICH frame structure [11]

The modulation process in WCDMA is performed in two stages: Channelization (Spreading) and scrambling. Spreading encodes the modulating data using orthogonal codes, increasing its bandwidth.

Channelization code in downlink (DL) separates physical channels of different users and common channels, defines physical channel bit rate whereas, channelization in uplink (UL) separates physical channel of one user, defines bit rate.

Scrambling uses pseudo-noise sequences to alter the order the data was applied to the modulator. Scrambling does not affect the signal bandwidth, but makes signals from different sources separable from each other. Scrambling in DL separates cells in the same carrier frequency whereas, it separates users in the UL. Detail of the canalization and scrambling codes are discussed in [16].

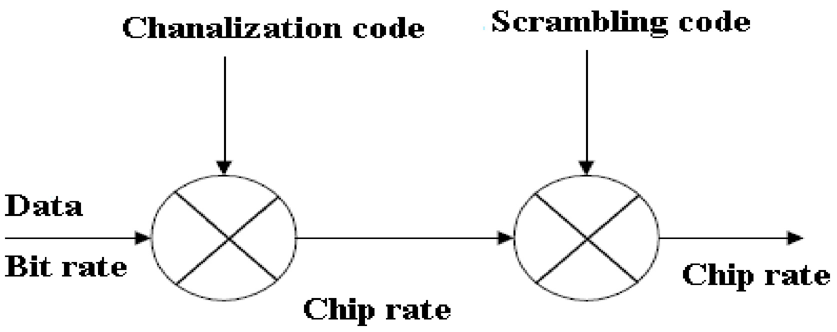


Figure 2-5: Spreading and scrambling schemes used in WCDMA [16]

2.3 UMTS/WCDMA Improvements

Compared to second-generation systems, one of the most important aspects of third-generation mobile systems is enhanced packet-data access. WCDMA Release 99 provides data rates of 384kbit/s for wide area coverage and up to 2 Mbit/s for hot-spot areas. This is sufficient for most existing packet-data applications [17]. However, as the use of packet data services increases and new services are introduced, greater capacity will be required. WCDMA Release 5 extends the specification with, among other things, a new downlink transport channel that enhances support for interactive, background, and to some extent, streaming services, yielding a considerable increase in capacity compared to Release 99 [17]. It also significantly reduces delay and provides peak data rates of up to **14** Mbit/s. This enhancement, come up with high speed downlink packet access (HSDPA), the first step of evolving WCDMA to provide even more outstanding performance.

3G was actually defined with fundamental improvements to both voice and data in mind. With respect to data, three design points were specified by the International Telecommunications Union (ITU):

- 144 Kbps when moving rapidly
- 384 Kbps when moving relatively slowly and
- Up to 2 Mbps when stationary or indoors

The ITU actually recognized a number of standards as meeting the definition of 3G, but UMTS having been developed by the European Telecommunications Standards Institute (ETSI), the people who invented GSM had a built-in advantage in the market and have now been deployed in many parts of the world for cellular communication supporting both qualitative voice communication and data communication.

2.4 The UMTS-R System and Services

2.4.1 Working Principle of the UMTS-R System

UMTS-R is a new radio access system proposed in this thesis for railway operation, which uses a WCDMA radio access system and is proposed to be applicable for the future railway system operation replacing the existing system (GSM-R) in most places across the globe.

Working principle of the System: A regional control system sends instructions to each train on a wireless medium and receives from on-board computer mounted in the trains. Those purposely installed Node Bs for UMTS-R system carries reliable voice and data services. On board computer provides signaling information and other value added services to the driver through the cab display.

Devices that are embedded in the track relay each trains location to the on board computer and should support the UMTS-R technology. Additional stuffs at dispatching, stations and control rooms should also communicate with the system by having UE that supports the technology. In general the system is expected to be safe, reliable, satisfactory and multiservice by taking the advantage of wideband property of WCDMA which helps to add more services and the concept of system and subsystem redundancy.

The system should be designed in a way that it should provide reliable and safe communication among different communicating parties including; dispatchers, shunting team, maintenance stuffs, recording center, cab radio (train), train control system and passenger service providing equipments across the railway operation system. Moreover, additional real time and non real time services that enhance safety in addition to entertaining services are the basic additional services of the system. . The graphical overview of the system is shown in figure (2-6) modified from GSM-R system in [9].

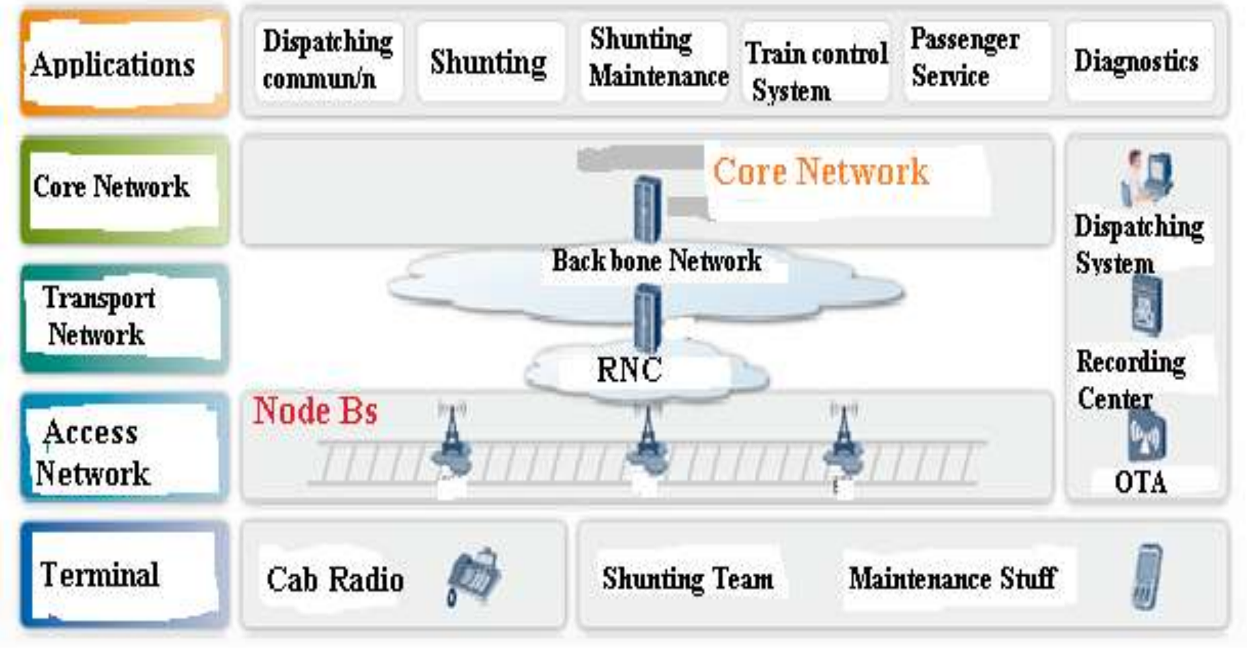


Figure 2-6: UMTS-R system overview modified from [19]

2.4.2 UMTS-R Services

This thesis is mainly applied to provide a better service in railway communication system by increasing the capacity and safety. The system should support all tasks that are done by GSM-R system in addition to new real time and non real time services that needs high data rate. The possible services of the system including GSM-R services taken from [3] are tabulated in table (2-3) below.

Table 2-3: UMTS-R functions and services supporting all GSM-R services in [3]

Emergency area broadcast	Electronic ticket system	Track side maintenance
Passenger transport broadcast system	Driver operation Communication	Remote control like door Opening and others
Wide area communication	Broad band wireless	Shunting
Freight transport Management	Local communication at stations and depots	Train support Communication
Video Surveillance	GPS based information system	SCADA surveillance System
Staff data support Applications	Real time passenger Information	Ticketing and seat Reservation
Signaling system	Dispatcher network (including public announcement systems)	Entertainment
Track side emergency phone system	Fixed telephony system	Passenger information and services

Additional operations based on the nature and service type of a route

Most of safety services, can be under any of the safety ensuring systems; Automatic Train Protection (ATP), Automatic Train Control (ATC) and Automatic Train Supervision (ATS) systems.

The detail deployment of the system will be done by dividing the whole system into five subsystems as shown in (figure 2-6) named as: applications layer, core network layer, transport layer, network access layer and terminal layer. The scope of the study is deeply concerned on the access network layer design. It notifies the coverage and capacity of the network across the case study route. Hence, the main concern of the study is on the node B which directly serves the terminal equipments of the system shown in figure 2-7.

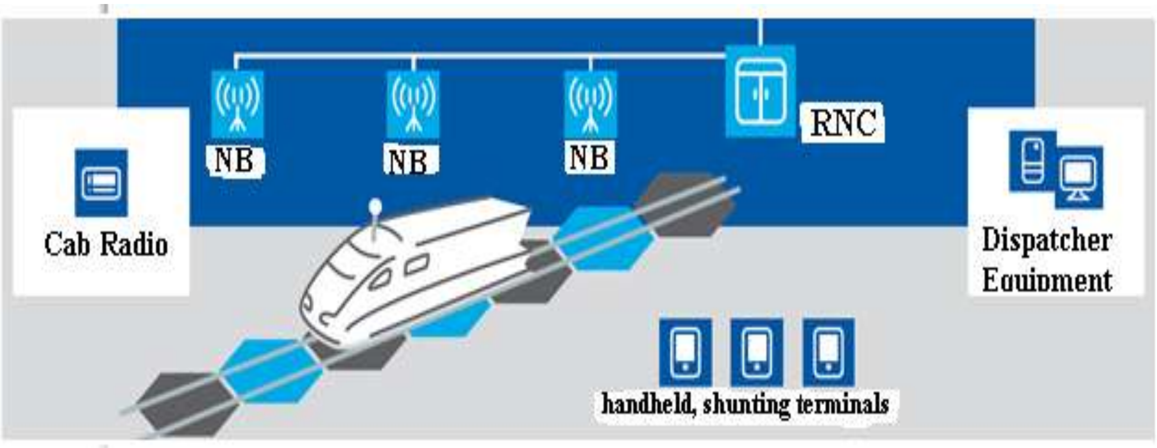


Figure 2-7: UMTS sub system which is the main concern of the study modified from [19]

2.5 Why Band Five?

The UMTS 850 MHz band is one of the 32 UMTS/FDD bands called band 5. This frequency among the other 31 bands, which some of them are reserved, is chosen reasonably for deploying UMTS-R capacity and coverage planning for the case study.

The first reason is 850MHz frequency is the first standard frequency band reserved for GSM-R by ETSI [19]. In the FDD mode , this band have **824 up to 849** MHz for the uplink (from UE to node B) and **869 up to 894** MHz for the downlink (from node B to UE) with a total bandwidth of 25 MHz and 45 MHz duplex gap. This band is a dedicated band to railway operators especially in Europe and some other countries have demonstrated its high quality and very good match for railway needs [19], even though GSM–R 900 MHz and GSM-R 1800MHz had proven their quality and reliability for railway capacity and coverage planning. Hence, designing a network capacity and planning at the standard frequency using WCDMA radio interface to increase the capacity and quality of service is considered as a better option.

The second reason why UMTS/WCDMA 850MHz is chosen is to have a better coverage. For the same parameters taken, the coverage radius of 850 MHz and 1950 MHz can be compared as tabulated in table (*2-4*) for 1950 MHz and (table 4-10) of section 4.2 rewritten as table (*2-5*) for 850 MHz. Different types of areas and data rates are considered to calculate their radius from the chosen propagation model; Okumura Hatta path loss model (section *4.2)*.

Table 2-4: Cell radius calculation for different areas and services at 1950 MHz [2]

Area	**Information (Kbps)**	**Allowed path loss (dB)**	**Cell range (Km)**	**Area (Km^2) (3 sector)**
Urban	Voice 12.2	141.9	1.42	5.24
	Data 144	133.8	0.79	1.62
Sub-urban	Voice 12.2	141.9	2.27	13.4
	Data 144	133.8	1.39	5.02

A considerable coverage difference is obtained by using the band 5 than other well known high frequency bands due to the fact that less frequency bands have less path loss which leads to have large area coverage. This is economically vital since it reduces the number of cells especially for routes that have less capacity. For the case of Addis Ababa – Djibouti railway route, whose area type considered as suburban and rural, coverage consideration is a key factor to ensure optimized cost. For comparison purpose, let us pick table 4-10 of section 4-2 here.

Table 2-5: calculated cell range magnitudes of the case study at 850 MHz frequency

<table>
<tr><td colspan="5">The maximum allowed propagation path loss for **12.2 Kbps** voice communication and 144Kbps data communication is 141.87dB and 137.76 dB respectively</td></tr>
<tr><th>Area</th><th>Information (Kbps)</th><th>Cell range (Km)</th><th>Area(Km^2)
(Omni-directional)</th><th>Area(Km^2)
(2 sector)</th></tr>
<tr><td>Urban</td><td>Voice 12.2</td><td>3.31</td><td>28.441</td><td>14.22</td></tr>
<tr><td></td><td>Data 144</td><td>2.5</td><td>16.267</td><td>8.133</td></tr>
<tr><td>Sub urban</td><td>Voice 12.2</td><td>6.43</td><td>107.32</td><td>53.66</td></tr>
<tr><td></td><td>Data 144</td><td>4.86</td><td>61.389</td><td>30.69</td></tr>
<tr><td>Rural semi-open</td><td>Voice 12.2</td><td>15.97</td><td>663.3</td><td>331.64</td></tr>
<tr><td></td><td>Data 144</td><td>12.08</td><td>379.4</td><td>189.7</td></tr>
<tr><td>Rural open</td><td>Voice 12.2</td><td>22.6</td><td>1326.67</td><td>663.34</td></tr>
<tr><td></td><td>Data 144</td><td>17.08</td><td>758.83</td><td>379.415</td></tr>
</table>

Generally, this new UMTS-R system provides better services including numerous value added services in addition to the main task which is ensuring safety and reliability. The main reason to increase the capacity which yields increasing service type across the railway system is due to the property of WCDMA which have wide available carrier bandwidth 5MHz which is 25 times wider than the existing GSM-R (200 KHz) service. This wide range bandwidth gives UMTS-R to be a better candidate of future railway network operation in terms of capacity. This thesis provides a redundant access layer sub system to ensure availability and reliability of coverage. Hence, it will be a solution to future railway system operation as system capacity and customer need increases.

Chapter Three

3. Nature and Personnel Forecasting of the Route

3.1 Addis Ababa-Djibouti Route Nature and Load

Addis Ababa-Djibouti route is located in the mountain areas between the central plateaus of Ethiopia and Djibouti border, the line originates from Sebeta at southwest of Addis Ababa and goes eastward through LABU, INDODE, GELAN, DUKEM, BISHOFTU, MOJO, ADAMA, WELENCHITI, METEHARA, AWASH, ASEBOT, MIESO, MULU, AFDEM, BIKE, GOTA, DIRE DAWA and DEWELE. The total distance of the route is 661.245km. The section from Sebeta to Mieso covers a distance of 327.245km and the route from Mieso to Dewele section covers 334km [3].

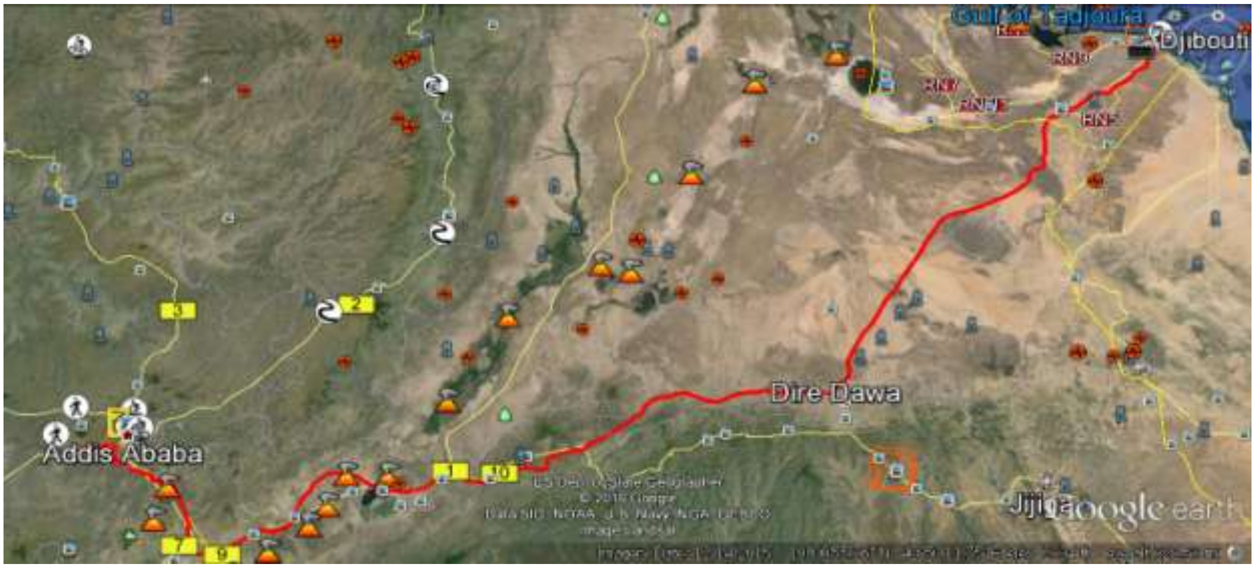


Figure 3-1: Addis Ababa-Djibouti Railway Route Crated at Google earth

The route passes through/around small towns and most of the area that the route passes is rural. The small towns to be considered as suburban that the route pass through or around collected from [18] are listed in the (table 3-1) below.

Table 3-1: the suburban areas found around the Addis Ababba – Djibouti route [20]

S.No.	**PLACE**	**LOCATION (CO-ORDINATE)**	**Geographical Location**
1	SEBETA	8° 55' 0" N, 38° 37' 0" E	South west of Addis Ababa
2	LABU	8° 29' 0" N, 38° 9' 0" E	West Shewa, Oromiya, Ethiopia
3	INDODE	8° 48' 0" N, 38° 31' 0" E	West Shewa, Oromiya, Ethiopia
4	GELAN	8° 52' 0" N, 37° 47' 0" E	West Shewa, Oromiya, Ethiopia
5	DUKEM	8° 48' 0" N, 38° 54' 0" E	Oromiya, Ethiopia, Africa
6	BISHOFTU	9° 6' 0" N, 37° 15' 0" East	West Shewa, Oromiya, Ethiopia
7	MOJO	8° 36' 0"N, 39° 7' 0" E	East Shewa, Oromiya, Ethiopia, Africa
8	ADAMA	8° 55' 0" N, 38° 55' 0" E Or 9° 32' 0" N, 38° 50' 0" E	North West Shewa, Oromiya, Or North West Shewa, Oromiya,
9	WELENCHITI	8° 40' 0" N, 39° 26' 0" E	North Shewa, Amhara, Ethiopia
10	METHARA	08°54′N 39°55′E	East showa Oromia, Ethiopia
11	AWASH	8° 59' 0" N, 40° 10' 0" E Or 8° 42' 0" N, 38° 37' 0" E	Afar_Three, Afar, Ethiopia, Africa Or West Shewa, Oromiya, Ethiopia
12	ASEBOT	9° 10' 0" N, 40° 40' 0" E	West Harerghe, Oromiya, Ethiopia
13	MI'ESO	9° 14' 0" N , 40° 45' 0" E	West Harerghe, Oromiya, Ethiopia
14	MULU	9° 17' 0" N, 40° 50' 0" E Or 9° 38' 0" N, 40° 48' 0" E	Afar_Three, Afar, Ethiopia, Africa Or Afar_Three, Afar, Ethiopia, Africa
15	AFDEM	9° 28' 0" N, 41° 0' 0" E	Afar_Three, Afar, Ethiopia, Africa

16	BIKE	9° 32' 0" N, 41° 12' 0" E	Afar_Three, Afar, Ethiopia, Africa
17	GOTA	9° 31' 0" N, 41° 20' 0" E	Afar_Three, Afar, Ethiopia, Africa
18	DIRE DAWA	9° 35' 0" N, 41° 52' 0" E	Shenile, Somali, Ethiopia, Africa
19	DEWELE	11° 2' 5" N, 42° 37' 53" E	Shenile, Somali, Ethiopia, Africa

The route is designed for both passenger and freight transport. Eight stations (SEBETA, LABU, BISHOFTU, MOJO, ADAMA, AWASH, MIESO and DAWANLE) will be arranged to deal with passenger transport business at preliminary stage. Whereas five stations (INDODE, MOJO, ADAMA, MIESO and DIRE DAWA) will be arranged to deal with freight transport business at preliminary stage. Others are general intermediate stations or crossing stations [3].

Looking at the nature of the route it accounts both double track and single track lines. The nature of the lines regarding to type of track, distance, and number of stations is stated on (table 3.2).

Table 3-2: The type of track with corresponding stations of short term design [3]

Line fraction (from – up to)	Length (Km)	Type of Track	Number of stations	Average distance between Stations (Km)
SEBETA – ADAMA	113.836	Double Track	7	16.26
ADAMA – MIESO	213.418	Single Track	12	17.78
MIESO – DEWELE	334.014	Single Track	21	15.91

The design of the route has three stages called: initial stage, short term stage and long terms stage. As shown on the table above, the total number of stations across the line is 21. This is the short term station number which will be achieved by 2025. On its initial stage it will account 16 substations and on the long term operation stage it is expected to have **40** stations in 2035. This thesis work will take a case study of this route on its long term case.

The expected passenger and freight flow of the line by dividing in to four sections on all the stages is documented on the design. It can be tabulated as follows.

Table 3-3: Fright flow of AA-Djibouti route measured in unit of 104 tones [3]

Station	Direction	2020	2025	2035
Indode – Adama	Up direction	530	780	1610
	Down direction	190	290	420
Adama – Awash	Up direction	439	697	1503
	Down direction	136	211	314
Awash – Dire dawa	Up direction	456	775	1653
	Down direction	144	238	351
Dire dawa – Dewele	Up direction	479	800	1700
	Down direction	148	242	358

The up direction is to mean direction from ***Dewele to Addis Ababba*** and is the heavily loaded direction. It is divided based on the current and future mobility of goods across the route. The fright flow density of short term is eight million ton, whereas at the long term it is seventeen million ton per year.

The passenger flow of the route taking the single line consideration is also documented for all the stages. The **Addis Ababba – Adama** section has the highest passenger density [21].

Table 3-4: Passenger flow density of single direction [22]

Section (from – up to)	**2020**	**2025**	**2035**
	Density of passengers (10,000 persons/ year)		
Addis Ababa – Adama	137.5	165	275
Adama –Dire dawa	55	55	82.5
Dire dawa –Dewele	27.5	27.5	55

3.2 Topographical and Morphological Nature of the Route

The long railway route taken as a case study in this thesis passes different topographical natures. Knowing the detail nature of the route is a critical task for the reliable network capacity and coverage planning. It helps to know where railway base stations (RBSs) should be configured, what height it should be, how far a single BS covers, what type of propagation model to apply and others mentioned on the detail planning process. In general the nature of the route is summarized in a tabulated form as shown below.

Table 3-5: The approximate geographical nature of the route [22]

Section	Nature of the Section	Availability of Vegetation /Forest
Sebeta – Mieso	Mountains, Hilly sections, more cities, 380m tunnel around awash	Moderate Forest available
Mieso – Dire dawa	Small Hills	Moderate Vegetation
Dire dawa – Adigala	Almost Flat Area (small hills)	No vegetation

The section from Meiso - Dewele also belongs to the Ethiopian plateau and it has shallow hilly landforms. Part of the zone has low mountains with river valleys and the ground is open and wide landforms. The elevation of track surface is ranging from 700m to 1200m, and the relative elevation difference is ten to twenty meters. Its climate is hot and the surface tropical plants are scarce with coverage of approximately 10% to 30%.

3.3 Existing Design Standard of the Route

The route consists of two types of track (double and single). The existing design standard is in (table 3-6) : Sebeta – Adama (double track) and Adama – Djibuti (single track).

Table 3-6: Technical standard of the route [21]

Parameter	**Sebeta – Adama**	**Adama – Djibuti**
Gauge	1435mm	1435mm
Number of main lines	**Double track**	**Single track**
Target speed value	Passenger train: 120Km/h Freight train: 80Km/h	Passenger train: 120Km/h Freight train: 80Km/h
Maximum grade	800m	800m
Algebraic difference of maximum Grade	Ruling grade 9%, pusher grade 18.5‰	Ruling grade 9%, pusher grade 18.5‰
Type of traction	Electric	Electric
Type of locomotive	SS4 freight train and SS9 passenger train	SS4 freight train and SS9 passenger train
Length of arrival and departure	850m (880 for dual locomotive)	850m (880 for dual locomotive)
Distance between center of track	4m	
Block Type	Semi Automatic	Semi Automatic

N.B: SS9 :- (Chinese **Shaoshan 9)** is a type of electric locomotive mainly used in pulling sub-high speed passenger train whereas, SS4 is a kind of AC-powered electric locomotives modeled in China.

3.4 Train Traffic and Personnel on the Route

The design of new network capacity and coverage takes a real data to the distribution of subscribers (UEs) at the target place. Hence, taking the distribution of the trains and personnel along the line will help to take a reliable assumption to the plan, especially for WCDMA planning which is sensitive to change in user's density.

Both the freight and passenger trains share the line at the same time. The quantitative distribution of those trains on different sections of the route taking the long stage only is given on (table 3-7*)*.

Table 3-7: Long term stage train capacity per day of Addis Ababa – Djibouti route [22]

Section	**Number of trains per day**				
	Passenger trains	Freight trains	Pick up and drop trains	Sub total	Required passing capacity
Sebeta – Adama	10	16	1	27	38
Adama –Awash	3	17	1	21	27
Awash-Diere dawa	3	19	1	23	30
Dire dawa – Dewele	2	19	1	22	28
Total	**18**	**71**	**4**	**93**	**123**

From the design specification, we can observe that the line can have 123 trains at maximum capacity operation. However, only 93 trains are allowed to flow at the route per day which implies the capacity of the route is 30 trains more than the long term existing design. This thesis will consider the maximum line capacity (**123** trains). By assuming the same ratio of the train types as given on (table *3-7)*, the remaining 30 trains will be (**5.806 (19.35%)** passenger trains, **22.903 (76.34%)** freight trains and **1.29** (**4.3%)** pickup and drop trains). Approximating the floating point numbers there will be **6** passenger trains, **23** freight trains and **1** pickup and drop additional trains for the operation of the route at the full required capacity. Hence, the total trains which will occupy the route per day at full system operation will be**: 24** passenger, **94** freight and **5** pickup and drop trains.

In addition to train and train system communication crew to train communication and communication among crews are also a basic task of safe railway operation. Hence, on designing network capacity and coverage planning the quantity and exact location of the crew for the case study should be considered.

Rolling stock depot management institution is set by Ethiopian Railway Corporation (ERC) at LABU to take charge of the administrative management of stations inside Ethiopia. The corporation sets up passenger transport department at the rolling stock depot of LABU, in charge of education and work management of the crew [3].

Due to lack of deep understanding about the local custom and living habits in Ethiopia and Djibouti, the accommodation or rest arrangement for the crew in the places, such as ADAMA, is not considered in the initial time, which will be determined by ERC during railway operation period, based on scheme of operating passenger train and the crew's demands [23]. Also the crew number will increase with some deviation due to some additional tasks. The list of personnel for the maximum line capacity at long term stage is forecasted as shown in (table 3-8).

Table 3-8: Total personnel of the whole line forecasted for long term stage modified from [3]

S/n	**Department**	**Quantity**
1	Company Management stuff	76
2	Rolling stock depot in LABU	54
3	Dispatching center stuff in LABU	63
4	Personnel of all stations in total	403
5	**Subtotal**	**536**
Additional Personnel due to additional 30 trains in this design		
1	Crew of unarranged stations like ADAMA, Djibouti	**157** (calculated from ratio of trains)
2	Additional crew for additional 30 trains	**223** (calculated from flat ratio) = 30*(536+157)/93
3	Deviation of additional stuff due to additional task that use the network (Assumption **5% of total**)	46
4	**Subtotal**	**426**
5	**Grand Total**	**962**

The result of table 3-8 shows as the number of personnel increases requiring additional network capacity across the route. The better existing technology (GSM-R) having a total capacity of around 7Mbps across the route [3] is incapable to provide reliable service for the new crew forecast.

3.5 Traffic Intensity of the New Forecast

Traffic intensity is a measure of the average occupancy of a server or resource during a specified period of time, normally at busy hour.

There will be forty (40) total number of running trains in the long term stage at pick hour in the section from Addis Ababa-Dewele. Since the running trains location signal (GPS signal) communicates with the BTS continuously, traffic intensity per train is 1Erlang. Therefore, the total traffic intensity is **40Erlang** [3].

For this case: The long term design mentions that 40 trains will use the line simultaneously at peak hour. As per the new forecast, additional 30 trains are assumed for the total line capacity and there will be additional trains on the line at the peak hour. Assuming flat ratio**, (30/93)*40 = 12.9 ~ 13** additional trains will be available at the line at peak hours. Hence, a total of **53** trains will be on the line at peak hours. Therefore, the traffic intensity of the GPS signal will be **53Erlang**.

In this study the main aim is to provide better railway system operation by upgrading the existing GSM-R system in to UMTS-R. All services provided by GSM-R system should be supported by this system. Information transfer of GSM-R network is given in (table *3-9*). This shows that much of the data used in the system is event driven. It is logical that increasing the dimension of the event driven information transfers and additional services like video surveillance will increase the reliability and safety of the railway system.

Table 3-9: Dimension and occurrence frequency of GSM-R network [22, 24]

S/N	Service (Data transfer)	Dimension	Transfer frequency
1	GPS location position signal	50 Byte	Per second
2	SMS	140 Byte	Event driven
3	Passenger Notification	500 Byte	Event driven
4	Alarms and Signals	10 Bytes	Event driven
5	Commands like door open – close system	3 Byte	Event driven
6	Reservation, Payment and baggage management	50KB	Event driven
7	Train events like harsh brake, block authority violation, curve, etc…	50 Byte	Event driven
8	Average transfer data files	1200 Bytes	Event driven
9	Voice data communication	2850 Bytes in full duplex and 1675 Bytes in half duplex	Event driven

The traffic intensity for each user of the network should be calculated for the case study on reliable data and scientific and worst case assumptions as follows:

Traffic Intensity of event driven tasks [3]

$$I(E) = T_{rmax} \times C_{ph} \times \frac{C_{du}}{3600} \qquad (3.1)$$

Where:

- **T_{rmax}** is maximum number of trains in the route
- **C_{ph}** is call frequency per hour
- **C_{du}** is duration of single call per second

In GSM-R system design C_{ph} value of 40 second and C_{du} = 30 seconds is considered for better operation [3]. Assuming the worst case that **C_{ph} = 50**, and **C_{du} = 40** seconds. The assumed increment of call per hour is due to increment in personnel across the route where as the increment of duration per call is due to the presence of additional services which the personnel are considering during the operation. Substituting the assumed values in to equation (3.1):

$$I(E) = 53 \times 50 \times \frac{40}{3600}$$

= **<u>29.44</u>** Erlang

There are also **962** people employed and will access the UMTS/WCDMA network continuously. The total traffic intensity value with zero blocking probability will be:

$$I(E) = (962 - 0) \times 12 \times \frac{30}{3600}$$

= <u>96.2 Erlang</u>

Where**, 12** is the frequency of call per hour, and **30** is the duration of each calls in second and **0** is blocking probability. The duration of each call (30 seconds) is taken from GSM-R standard [3].

There are 260 yards, blocks, interlocking and station signaling systems in the long term stage of the route, and the path also incorporated 80 level crossing signals. Thus, total signaling system of the route in quantity is **340**. Assuming that those signaling systems are enough for long term stage even with the added 30 trains by optimizing our scheduling time, the signaling system intensity value similarly becomes:

$$I(E) = (340 - 0) * 4 * \frac{15}{3600}$$

= <u>5.6666 Erlang</u>

Where**, 4** is the frequency of call per hour, and **15** is the duration of each calls in second [3] and **0** is blocking probability.

The reason why a zero blocking probability is assumed is to ensure safety. Due to the high speed nature of moving trains, every call should pass without blocking so that safety is not compromised.

Chapter Four

4. UMTS-R Design Process

4.1 UMTS/WCDMA Network Planning

WCDMA planning is an iterative process which includes pre-planning, detailed planning and adjustment to optimize and meet the requirement.

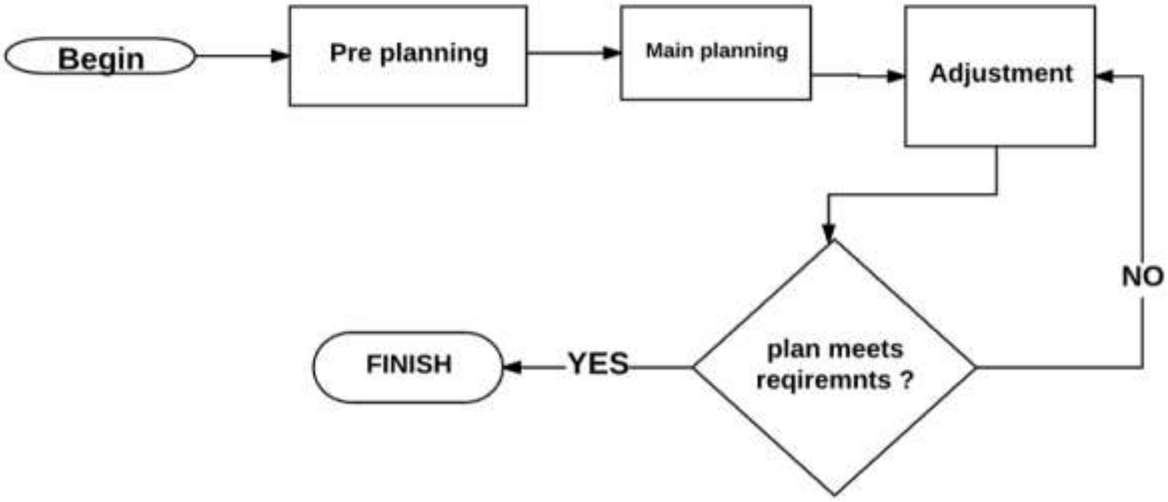


Figure 4-1: Overview of WCDMA radio planning iteration

The pre planning stage includes preparing necessary data to the case study. For the case study, due to absence of digital map regarding to Addis Ababa – Djibouti a route is prepared in Google earth and prepared to be used in the detail (main) planning. WCDMA main (detailed) network planning includes dimensioning, detailed capacity and coverage planning and network optimization based on the choice of node B geographical site [6]. The detailed (main) network planning of WCDMA radio access mechanism can be summarized in figure *4-2* below.

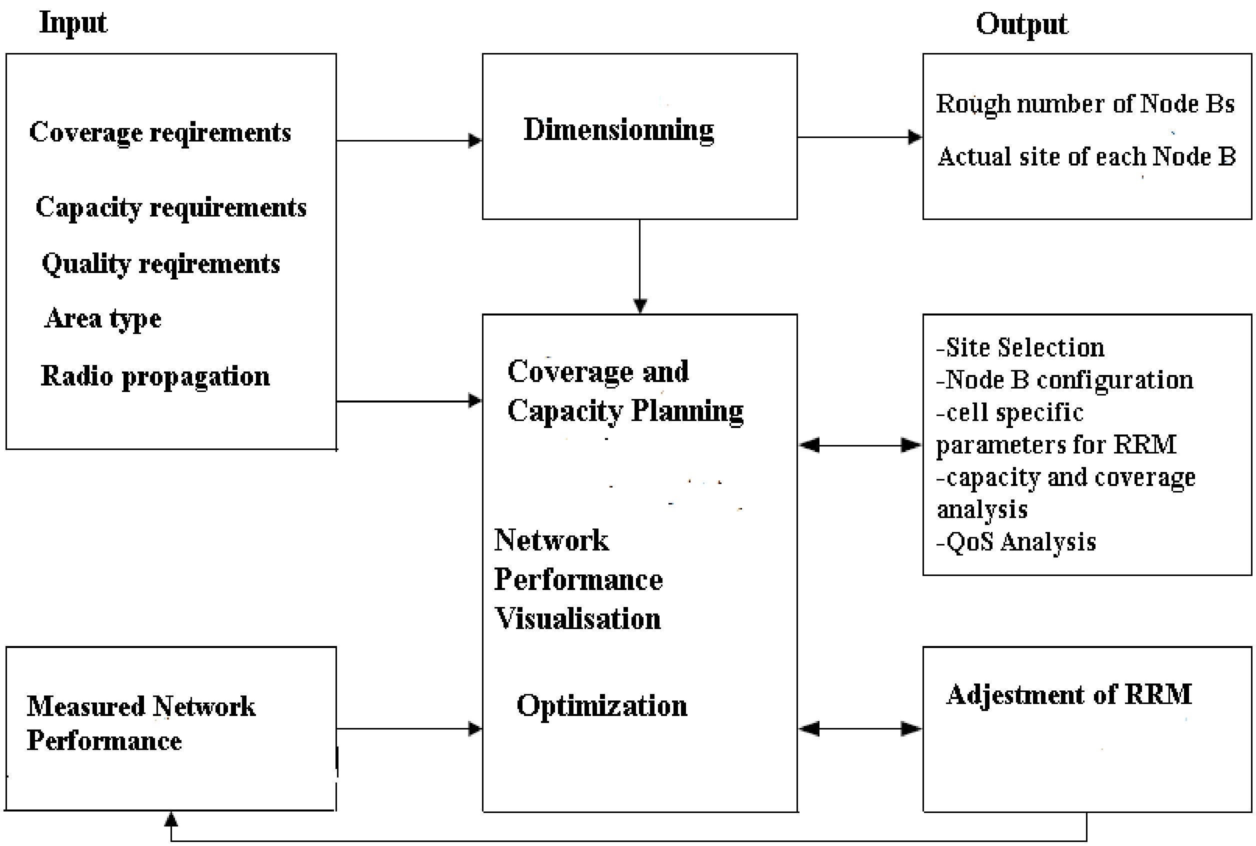


Figure 4-2: WCDMA detail radio network planning process

4.1.1 Dimensioning

Dimensioning is the first step in WCDMA radio network planning step which involves estimating the approximate number of Node B sites, RNCs, Node Bs and network elements in addition to core network based on the network operator's requirement and type of the area. The dimensioning process should fulfill the requirements of the operator for capacity, coverage and **QoS**. In WCDMA, capacity and coverage are closely related and must be considered simultaneously [6].

Hence, in WCDMA, radio network dimensioning is a critical step that should estimate parameters, so that the detailed planning achieves better throughput. Link budget analysis; accounting of all the gains and losses from the transmitter is done in this section.

Regarding to coverage, coverage regions, area type information and propagation conditions should be estimated in dimensioning process. Traffic density information, subscriber growth forecast and spectrum available estimations also belong to capacity [6]. Finally a designed network should have a certain acceptable quality.

4.1.2 Radio Link Budget

Radio link budget calculation in UMTS/WCDMA involves certain steps [25]. The starting point of a link budget calculation is to define the required data rate(s) in each network areas and **E_b/N_o** (Energy per Bit to Noise power density ratio) targets.

The next step is to gather vendor specific data like a BTS output power and a receiver noise figure, defined and used cable systems, used antenna types, usage of intelligent antenna systems in specific areas, possible additional line amplifiers, used diversities (like antenna, polarization, receiver) etc. For each geographical areas network operator has to define E_b/N_o, data services, a system loading factor, estimated mobile speeds, different penetration losses, coverage reliability and a used fade margin [6].

Mobile power levels, the chip rate and the process gains are defined by the UMTS standards. Some link budget parameters like soft handover gain and the thermal noise density are the same in every UMTS system [16].

The link budget gives a cell range and from that cell coverage area can be calculated. After all, the base station requirements for each type of areas can be calculated.

Unlike link budget of TDMA based radio access systems like GSM, there are WCDMA specific parameters including:

Fast Fading Margin: - is a fast design allowance that provides for sufficient system gain or sensitivity to accommodate expected fading, for the purpose of ensuring that the required QoS is maintained [26]. It is power control headroom needed at the mobile station transmission power for maintaining closed loop fast power control. This applies especially to slow-moving pedestrian mobiles where fast power control is able to effectively compensate the fast fading and the typical value is 2.00 – 5.00 dB [6]. For fast moving users, (***120 Km/h and above***) no fast fading margin is needed to be reserved since the fast power control is unable to compensate for the fading.

Interference Margin: - is the increased noise level caused by greater load in a cell. Coverage of a cell is affected by load factor, the reason for the availability of interference margin in WCDMA link budget. The more loading is allowed in the system, the larger is the interference margin needed in the uplink, and the smaller is the coverage area. For coverage-limited cases a smaller interference margin is suggested, while in capacity-limited cases a larger interference margin should be used. Typical values for the interference margin in the coverage-limited cases are 1.0−3.0 dB, corresponding to 20−50% loading [6].

Soft Handover Gain: - handover (hard or soft) gives a gain against slow fading (log-normal fading) by reducing the required log - normal fading margin. Soft handover gives an additional macro diversity gain against fast fading by reducing the required E_b/N_o relative to a single radio link, due to the effect of macro diversity combining. The total soft handover gain is assumed to be between 2.0 and 3.0 dB [6]. The value of gain mainly depends on mobile speed and diversity combining algorithm.

4.1.2.1 Link Budget for the Case Study

Link budget analysis includes assumed values from the standard releases, calculated values and real geographical surveyed data (regarding to environment type and node B site location) taken from Google earth. It is also designed for different services and data rates.

UMTS is able to offer different data rates for multiple services. UMTS offers different standard bit rates as shown on the table (4-1) of service class below.

Table 4-1: Standard speed class of WCDMA for UMTS service [27]

Bit rate (kbps)	Class
384	Class 1
144	Class 2
64	Class 3
32	Class 4
12.2	Class 5

The difference in the service class has an impact on the coverage of the network. Higher class of service makes cell radius small which results in reducing the coverage area as shown on figure 4-3.

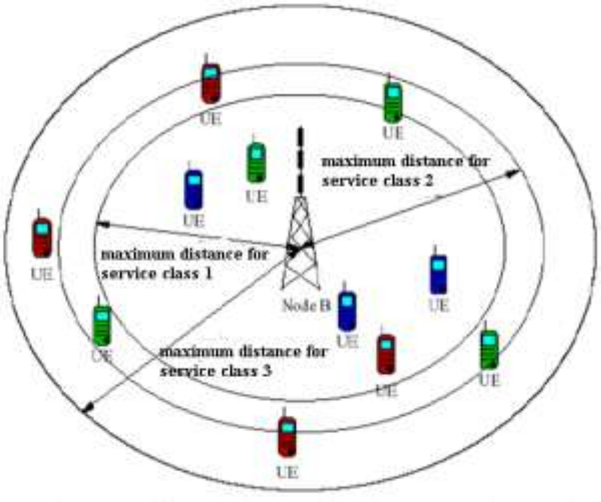


Figure 4-3: Different standard services class Vs maximum distance [27]

Hence, optimizing the coverage area and maintaining an acceptable data rate is one of the challenges that engineers have to meet in designing UMTS/WCDMA network.

The case study is to be analyzed for a maximum operational speed of 120 Km/h in train UE in addition to other stationary UEs like control rooms. Different data rates are considered. Class 5 (12.2) Kbps for voice communication and class 2 (144 kbps) for packet switched data are assumed in the link budget calculation. However, class 1 (384 Kbps) can be considered for non real time data services. In most WCDMA systems there are network parameters that are taken from releases, studies and standards. This thesis takes most widely used common parameters at case of high speed moving subscribers to fit the case study of 120 Km/h tabulated in tables 4-2 and 4-3 below.

Table 4-2: Standard Assumptions for mobile stations (UE) [6, 27]

Parameter	Speech terminal	Data Terminal
Maximum transmission power	21 dBm	24 dBm
Antenna gain	0 dBi	2dBi
Body loss	3dB	0 dB

As per the standard of 3GPP, standard known assumed design parameters for UE (MS) and Node B for better quality is taken in to assumption and is listed in tables 4-2 and 4-3 respectively [28].

Table 4-3: Assumptions for Node B [6, 27]

Parameter	Speech terminal	Data Terminal
Noise figure	5 dB	5 dB
Antenna gain	18dBi	18dBi
E_b/N_o requirement	5 dB	2 dB
Cable loss	2 dB	2 dB

Hence, two link budgets will be calculated for two different services (data rates). The first link budget is the class 5 (12.2Kbps) data rate designed for 120 Km/h running in-train users with soft handover. The link budget establishment for coverage, capacity and optimization reasons also enables the estimation of the allowed maximum propagation loss L_{pmax} A common parameter between propagation models and link budget algorithms is the path loss, L_P [29].

$$L_{pmax}\,[dB] = P_t[dBm] + G_t[dBi] + G_r[dBi] + G_{SH}[dB] - R_{Smin}\,[dBm] - \sum L_x[dB] - \sum F_m[dB] \qquad \mathbf{(4.1)}$$

Where,

L_{Pmax} is the maximum propagation loss allowed for a given service

P_t is the transmitted power (delivered to the antenna)

P_{Tx} is the transmitter output power

P_r is the antenna received power

G_t is the maximum transmitter antenna gain

G_r is the maximum receiver antenna gain

G_{SH} is the soft handover gain

R_{Smin} is the receiver sensitivity for a given service bearer

L_x represents additional attenuations in a link, which may be user body loss L_{UB}, cable loss L_C, and others (car loss) L_{Other}.

F_M represents fading margins, i.e., fast fading margin F_{FM}, and slow fading margin F_{SM}.

Also the Equivalent Isotropic Radiated Power (**EIRP**), depends on P_t and G_t as follows:

$$EIRP[dBm] = P_t[dBm] + G_t[dBi] \tag{4.2}$$

Where P_t is defined by

$$P_t[dBm] = P_{tx}[dBm] - L_c[dBm] \tag{4.3}$$

And P_{rx} is given by

$$P_{Rx}[dBm] = P_r[dBm] - L_c[dBm] \tag{4.4}$$

A major parameter in radio network planning is $\boldsymbol{R_{Smin}}$, because it depends on the service type (energy of bit over noise and bit rate), therefore, different $\boldsymbol{L_{Pmax}}$ and cell radius are expected for each service. The equation can be expressed in short as: [1]

$$R_{smin}\ [dBm] = \left(\frac{E_b}{N_o}\ [dB]\right) - G_p\ [dB] + N[dBm] \tag{4.5}$$

Where, G_p is the processing gain in dB and N is the effective noise and interference in dBm

4.1.2.2 Link budget of 12.2 Kbps

4.1.2.2.1 MS (UE) part

Equivalent Isotropic Radiated Power (EIRP)

EIRP alternatively, **effective isotropic radiated power** is the amount of power that a theoretical isotropic antenna (which evenly distributes power in all directions) would emit to produce the peak power density observed in the direction of maximum antenna gain given in equation (4.2).

Where,

$\mathbf{P_{Tx}}$ is the maximum mobile power in dBm (21 dBm)

$\mathbf{G_t}$ is the mobile antenna gain in dBi (0.0dBi)

$\mathbf{L_C}$ is the body loss in dB (3dB)

Hence, substituting those values in to equation (3.11) will yield:

$$\boldsymbol{EIRP = 21 + 0.0 - 3 = 18\ dBm}$$

- **WCDMA UL interference**

During the signal propagation there is interference from other users. Summing up all the signals other than the target user together are called interferences and are determined by the parameter Signal to Interference Ratio (SIR) calculated for the UL case as shown in equation (4.6) [29].

$$\boldsymbol{SIR_{UL}} = \frac{\boldsymbol{G_p * S}}{(\boldsymbol{1-\beta}) * \mathrm{I}_{intra} + I_{inter} + N_o} \tag{4.6}$$

Where,

$\boldsymbol{G_p}$ is the processing gain

$\boldsymbol{S}$ is the received signal

$\boldsymbol{I_{Intra}}$ is interference generated by those users that are connected to the same BS

$\boldsymbol{I_{Inter}}$ is interference from other cells

$\boldsymbol{N_0}$ is thermal noise, which may be neglected when compared with interference levels

β is an interference reduction factor due to the use of, for example, Multiuser Detection (MUD).

A rough estimation of intra-cell interference is made as (**$\boldsymbol{I_{Intra}}$ = S*N). Where**, ***N*** is the number of users that are associated or connected to a given node B.

Let a fraction F is written as the ratio of intra-cell interference to total interference (intra and inter cell)

$$F = \frac{I_{Intra}}{I_{Intra} + I_{Inter}} \tag{4.7}$$

A simulated result of **F** for macro-cells is about <u>**0.73**</u> **[**30**].** Hence, if one of the interference values (inter cell or intra cell interference) is known, the other value can be computed.

4.1.2.3 Node B part

- <u>**Node B sensitivity**</u>

The node B receives power (**P_R**) from UE to make a communication. Hence, this minimum signal power at the input of the node B receiver is called **sensitivity**. It must meet the requirements of E_b/N_o, Processing gain (G_p), node B interference and noise power.

$$\boldsymbol{Node\ B_{sensitivity}} = {}^{E_b}/_{N_o} - G_p + \boldsymbol{N_{node\ B\ interference\ and\ noise\ power}} \tag{4.8}$$

Where,

$\boldsymbol{E_b/N_0}$ is a relation between energy of bit and **noise density which depends on** the service, mobile speed, receiver algorithms and node B antenna structure

$\boldsymbol{G_p}$ is the processing gain given by:

$$G_p = 10\log\left(\frac{W}{R}\right) = 10\log\left(\frac{3.84 * 10^6}{R}\right) \quad (4.9)$$

where **R** is the bit rate and **W** is the chip rate

N is the total effective noise plus interference power which can be written as: [29]

$$N[dBm] = 10\log(10^{\frac{Rn\,[dBm]}{10}} + 10^{\frac{Ri\,[dBm]}{10}}) \quad (4.10)$$

Where, ***R***

Where, $\boldsymbol{R_n}$ is the receiver noise power and $\boldsymbol{R_i}$ is receiver interference power given by: [29]

$$R_n = R_{no}\,[dBm/hz] + 10\log[3.84 * 10^6\,[cps] \quad (4.11)$$

$$R_i[dBm] = 10\,log\left(10^{\frac{Rn\,[dBm]+Im\,[dB]}{10}} - 10^{\frac{Rn\,[dBm]}{10}}\right) \quad (4.12)$$

Where,

$\boldsymbol{I_m}$ is the interference margin and

$\boldsymbol{R_{nO}}$ is the receiver noise density

The receiver noise density, $\boldsymbol{R_{nO}}$ depends on the thermal noise density $\boldsymbol{N_o}$ and on the noise factor**,** $\boldsymbol{F_n}$

$$R_{no}\,[dBm/hz] = N_o\left[{}^{dBm}/_{hz}\right] + F_n\,[dB] \quad (4.13)$$

Hence, Using propagation models and link budgets algorithms, it is possible to estimate the **interference load in a given area**, therefore in a given cell (Node B). To estimate the amount of supported traffic (capacity) per cell, it is very important to calculate the interference, because cellular systems that use a frequency reuse factor of **1** are typically strongly interference-limited by the air interface.

WCDMA DL Interference

According to [26], the Signal to Interference Ratio for the downlink is given as:

$$SIR_{Dl} = \frac{S * G_p}{\alpha * I_{intra} + I_{inter} + N_o} \quad (4.14)$$

N.B: The orthogonal factor **α** takes into account the fact that the DL is not perfectly orthogonal due to **multipath propagation**; an orthogonal factor of **0** corresponds to perfectly orthogonal intra-cell users, while for the value of 1, intra-cell interference has the same effect as inter-cell one. The standard [31] simulation result of orthogonal factor **α** for maximum transmitted power is given on table 4.4.

Table 4-4: Values of α for maximum power transmission [31]

Environment	$\boldsymbol{\alpha}$ **value**	**Total max. BS TX power [dBm]**
Macro-cell	0.4	43
Micro-cell	0.06	33

Compared to a micro-cellular environment, a signal in macro-cellular one follows a more complex path, which is translated into a more complex multipath; because of these higher distances (more reflection and refraction points), the **α** factor in a macro-cellular environment is expected to be higher than in a micro-cellular one [30].

Calculating by substituting the values to the equations mentioned in the previous sections will yield:

- **Thermal noise density** (η)

  $$\boldsymbol{\eta = KT} \qquad (4.15)$$

  Where,

  K is Boltzmann's constant $=1.381 \times 10^{-23}$ J/K

  T is a temperature of UE and is 290 ˚K, a standard value for all WCDMA based networks [5]

Hence substituting the values in to equation (4.14), will yield $\boldsymbol{\eta = -174 dBm/Hz,}$ a standard value for all WCDMA based networks.

- Receiver noise figure **(F_n = 5dB)**
- Required **E_b/N_o (5 dB)**
- Interference margin **(3 dB)**
- Receiver noise density

$$R_{no}\,[dBm/hz] = N_o\left[{}^{dBm}\!/_{hz}\right] + F_n\;[dB]$$

$$\boldsymbol{= -174 + 5 = -169\;dBm/hz}$$

- Receiver noise power

$$R_n = R_{no}\,[dBm/hz] + 10\log[3.84 * 10^6\;[cps]$$

=-169 +10*log 3.84 + 60

<u>R_n= -103.156 dBm</u>

- **Receiver interference power**

$$R_i[dBm] = 10\,log\left(10^{\frac{Rn\,[dBm\,]+Im\,[dB\,]}{10}} - 10^{\frac{Rn\,[dBm\,]}{10}}\right)$$

$$\underline{\boldsymbol{R_i = -103.2dBm}}$$

- **Processing gain**

$$G_p = 10\log\left(\frac{W}{R}\right) = 10\log\left(\frac{W}{R}\right)$$

$$G_p = 10\log_{10}\frac{384000}{12200}$$

= 24.97 dB

- **Total effective noise and interference**

$$N[dBm] = 10\log\,(10^{\frac{Rn\,[dBm\,]}{10}} + 10^{\frac{Ri\,[dBm\,]}{10}})$$

$$\boldsymbol{N_{node\;B\;interference\;and\;noise\;power} = -100.2\;dBm}$$

- **Receiver sensitivity**

$$\boldsymbol{Node\;B_{sensitivity}} = {}^{E_b}\!/_{N_o} - G_p + \boldsymbol{N_{node\;B\;interference\;and\;noise\;power}}$$

$$= 5 - 24.97 - 100.2$$

$$\boldsymbol{Node\;B_{sensitivity} = -120.17\;dBm =\cong -120.2dBm}$$

- Node B antenna gain = **18 dBi**
- Cable loss in the Node B = **2dB**
- Fast fading margin **is = 0**, considering at high speed.
- Maximum path loss

$$L_{pmax}\;[dB] = P_t[dBm] + G_t[dBi] + G_r[dBi] + G_{SH}[dB] - R_{Smin}\;[dBm]$$
$$- \sum L_x[dB] - \sum F_m[dB]$$

$$= EIRP - \ Node\ B_{sensitivity} + \ G_t - \ Cable\ loss - fast\ fading\ margin$$

$$= 18 + 120.17 + 18 - 2 - 0$$

$$\boldsymbol{L_{pmax}[dB] = 154.17}$$

Where,

$\boldsymbol{dBi}$ *is the gain in dB of an isotropic antenna* $(i$ *stands for isotropic*$)$

$\boldsymbol{dBm}$ *is the power ratio in decibels refereced to one milliwatt*

- Log normal fading constant = 7 dB
- Propagation model exponent = 3.52
- Log normal fading margin = 7.3 dB
- Soft handover gain = 3dB
- In train loss = 8dB
- Allowed propagation loss for cell range

$$L_{AP} = \ L_{pmax}[dB] - \ FM_{ln} + G_{SH} - \ L_T$$

$$= 154.17 - 7.3 + 3 - 8$$

$$\boldsymbol{L_{AP} = 141.87\ dB}$$

Where,

$\mathbf{L_{AP}}$ is the allowed propagation loss

$\mathbf{FM_{ln}}$ is the log normal fading margin

$\mathbf{L_T}$ is train loss and

$\mathbf{G_{SH}}$ is the soft handover gain

Hence, collecting all the calculated values, the link budget for the 12.2Kbps can be tabulated in table (4-5).

Table 4-5: WCDMA link budget for voice service of the case study

UMTS/WCDMA 850MHz Link Budget		
Case study of Addis Ababba – Djibouti railway route		
12.2 Kbps voice service (120Km/h in- train users)		
The UL (mobile station) part		
Parameter	**Magnitude**	**Unit**
Maximum mobile transmission power	21/0.125	dBm/W
Mobile antenna gain	0.0	dBi
Body loss	3	dB
EIRP	18	dBm
The DL (NodeB) part		
Base station receiver noise figure	5	dB
Node B ntenna Gain	18	dBi
E_b/N_o requirement	5	dB
Cable loss	2	dB
Thermal noise density	-174	dBm/Hz
Interference margin	3	dB
Receiver noise density	-169	dBm/Hz
Receiver noise power	-103.156	dBm
Receiver interference power	-103.2	dBm
Processing gain	24.97	dB
Total effective noise and interference	**-100.2**	**dBm**
Node B receiver sensitivity	-120.17	dBm
Cable loss in the node B	2	dB

Fast fading margin	0	dB
Maximum path loss	**154.17**	**dB**
Log normal fading constant	7	dB
Propagation model exponent	3.52	
Soft handover gain	3	dB
Allowed propagation loss for cell range	**141.87**	**dB**

4.1.2.4 Link Budget of 144Kbps

Similar calculations are to be made for the data terminal link budget both in UL and DL case and the tabular form of the typical link budget at a data rate of 144kbps with soft handover is shown in table *(4-6)* below:

4.1.2.4.1 UE (UL) part

- Maximum mobile transmission power **(W/dBm) = 0.25 W or 24 dBm**
- Mobile antenna gain = 2 dBi
- Body loss = 0.0 dB, assumption is taken that there is no loss at the body of the data terminal (UE).
- Equivalent Isotropic Radiated Power (EIRP), applying equation (*4.2) above*

$$EIRP[dBm] = P_t[dBm] + G_t[dBi] - body\ loss$$

$$= 24dbm + 2dbi - 0$$

$$= \mathbf{26\ dBm}$$

4.1.2.4.2 Node B (DL) Part

- Thermal noise density

Similar calculation as the 12.2kbps data rate is done and the value is = **-174** dBm/Hz

- Node B receiver noise figure = 5 dB
- Receiver noise density

$$R_{no}\,[dBm/hz] = N_o\left[{}^{dBm}/_{hz}\right] + F_n\ [dB]$$

= -174dBm/Hz +5dB

= -169 dBm/Hz

- Receiver noise power

$$R_n = R_{no}\,[dBm/hz] + 10\log[3.84 * 10^6\ [cps]$$

$$= -169 + 10\log 3.84 + 60$$

$$\mathbf{= -103.156\ dBm/Hz}$$

- Interference margin = 3 dB
- Receiver interference power

$$R_i[dBm] = 10 * log\left(10^{\frac{Rn\,[dBm\,]+Im\,[dB\,]}{10}} - 10^{\frac{Rn\,[dBm\,]}{10}}\right)$$

$$= 10*\log(10^{(-103.156+3)/10} - 10^{-103.156/10})$$

$$= \mathbf{-103.156}$$

- Total effective noise and interference

  Similar as for the 12.2Kbps case = **-100.2 dBm**
- Required **E_b/N_o = 1.5 dB**

$$N[dBm] = 10\log(10^{\frac{Rn\,[dBm\,]}{10}} + 10^{\frac{Ri\,[dBm\,]}{10}})$$

$$= 10\ log\left(10^{-103.156/10} + 10^{-103.156/10}\right)$$

$$= \mathbf{-100.2dBm}$$

- Processing gain

$$G_p = 10\log\left(\frac{W}{R}\right) = 10\log\left(\frac{W}{R}\right)$$

$$= 10\ log\left(\frac{3840}{144}\right)$$

$$= \mathbf{14.26\ dB}$$

- Node B antenna gain **= 18 dBi**
- Receiver sensitivity

$$Node\ B_{sensitivity} = {}^{E_b}/_{N_o} - G_p + N_{node\ \ B\ interference\ \ \ and\ \ noise\ \ power}$$

$$= 1.5 - 14.26 - 100.2dBm$$

$$= \mathbf{-112.96\ dBm}$$

- Node B cable loss = **2 dB**

- Fast fading margin = **0.0dB**, high speed is considered in case of railway. Assumptions are taken that data communication among control rooms, dispatchers, stations and other real/non real time data services with a fast moving train at a speed of 120Km/h.
- **Maximum path loss**

$$L_{pmax}\ [dB] = P_t\,[dBm] + G_t\,[dBi] + \ G_r\,[dBi] + \ G_{SH}\,[dB] - \ R_{Smin}\ [dBm] - \sum L_x\,[dB] - \ \sum F_m\,[dB]$$

$$= 26 + 112.96\ \text{dBm} + 18\ \text{dBi} - 2\text{dB} - 0$$

$$\mathbf{= 154.96\ dB}$$

- Coverage probability = 75%
- Log normal fading constant = 7dB
- Propagation model exponent = 3.52
- Log normal fading margin 4.2dB
- Soft handover gain =3dB
- Indoor loss = 15 dB
- Allowed propagation loss for cell range

$$L_{AP} = \ L_{pmax}[dB] - \ FM_{ln} + G_{SH} - \ L_T$$

$$= 154.96 - 4.2 + 3 - 15dB$$

$$\mathbf{= 137.76\ dB}$$

Hence, collecting all the calculated values, the link budget for the 144 Kbps can be tabulated as in table 4-6 below.

Table 4-6: WCDMA link budget for data service of the case study

UMTS/WCDMA 850MHz Link Budget		
Case study of Addis Ababba – Djibouti railway route		
144 Kbps voice service (120Km/h in- train users)		
The UL(mobile station) part		
Parameter	**Magnitude**	**Unit**
Maximum mobile transmission power	21/0.125	dBm/W
Mobile antenna gain	0.0	dBi
Body loss	0.0	dB
EIRP	26	dBm
The DL (NodeB) part		
Max. Node B transmission power	43	dBm
Node B receiver noise figure	5	dB
Node B antenna Gain	18	dBi
E_b/N_o requirement	5	dB
Cable loss	2	dB
Thermal noise density	-174	dBm/Hz
Interference margin	3	dB
Receiver noise density	-169	dBm/Hz
Receiver noise power	-103.156	dBm
Receiver interference power	-103.156	dBm
Processing gain	14.26	dB

Total effective noise and interference	**-100.2**	**dBm**
Node B receiver sensitivity	-120.17	dBm
Cable loss in the node B	2	dB
Fast fading margin	0	“
Maximum path loss	**154.96**	**dB**
Log normal fading constant	7	dB
Propagation model exponent	3.52	
Log normal fading margin	4.2	dB
Soft handover gain	3	dB
Allowed propagation loss for cell range	**137.76**	**dB**

The only difference between link budget of class 1 (384 Kbps) and class 2 (144 Kbps) data rates are the difference in processing gain, a higher mobile transmission power and a lower $\boldsymbol{E_b/N_o}$ requirement on the first one [6].

The coverage efficiency of WCDMA is defined by the average coverage area per site, in **km^2/site**, for a predefined reference propagation environment and supported traffic density [28]. From the link budgets above, the cell range R can be readily calculated for a known chosen propagation model.

4.2 Radio Propagation Model

Radio propagation model is an empirical mathematical formulation for the characterization of **radio** wave **propagation** as a function of frequency, distance and other parameters. A single model is usually developed to predict the behavior of propagation for all similar links under similar constraints and typically predicts the path loss along a link or the effective coverage area of the transmitter.

4.2.1 Path Loss

Path loss is the reduction in power density of an electromagnetic wave as it propagates through space [32]. There are fast (Rayleigh) and slow (log-normal) fading. Fast fading occurs due to fast movement of train, signal collision with towers and trees [3]. Slow fading arises when the coherence time of the channel is large relative to the delay constraint of the channel. Slow fading can be caused by events such as shadowing, where large building obscures the main signal path between the transmitter and the receiver [2]. Hence different path loss models were proposed by scholars and are applied in different system designs based on their properties and assumptions they have used. The most frequently empirical path loss models with their corresponding path loss equations for the case of rural and sub-urban environments are tabulated in table (4-7) below.

Table 4-7: Frequently used path loss models and their path loss equations

S/N	**Name of Propagation model**	**Path Loss Equation** **(Sub urban path loss ($P_l(SU)$) and rural path loss ($P_l(R)$))**	**Recommended range of frequency (MHz)**	**Remark**
1	**Okumura**	$P_l(U) = L_{fs} + A_{ul} + H_{txf} + H_{rxf}$	200 up to 1920	Mostly used in Urban
2	**Cost 231 –Hatta**	$P_l(SU) = P_l(R) = 46.3 + 20.08\log_{10} H_t - \alpha_{(Hr)} + (44.9 - 6.55\log_{10} H_t)\times\log_{10} R$	Around 900 and 1800	Can be applied in any environment
3	**Okumura –Hatta**	$P_l(SU) = 69.5 + 26.16\log_{10} f + [44.9 - 6.55\log_{10} H_b]\log_{10} R - 13.82\log_{10} H_b - \alpha(H_m) - 9.794dB$ $P_l(R) = 69.55 + 26.16\log_{10} f + [44.9 - 6.55\log_{10} H_b]\times\log_{10} R - 13.82\log_{10} H_b - \alpha(H_m) - 23.2\,dB$	Mainly 150 up to 1500	Gives correction factors for suburban and rural areas
4	**Stamford University Interim** **(SUI)**	$P_l(U) = P_l(SU) = P_l(R) = A + 10\gamma + \log\left(\frac{d}{d_o}\right) + X_f + X_m + S$	Mainly 2500 up to 2700	Mainly for microwave communication

Where,

$P_l(U)$ is the urban path loss

L_{fs} is Free space path loss given by

$$L_{fs} = 32.45 + 20\times\log\left(\frac{d}{1Km}\right) + 20\log\left(\frac{f}{1Mhz}\right) - 10\times\log G_t - 10\times\log G_r \quad [33] \qquad (4.16)$$

d is the distance between the transmitter and receiver in Km

f is operating frequency

$\mathbf{G_t}$ the transmitting antenna gain and $\mathbf{G_r}$ is the reciving antenna gain

with typical values of 18dB for transmitter, 0db forportable MS and 2dB for CAB radios

$\mathbf{A_{ul}}$ is basic median attenuation which is an additional loss due to propagation in urban area.

for the cases study this is 0dB due to no urban area in the route.

$\mathbf{H_{txf}}$ transmitter height correction factor in dB (-18dB) [22]

$\mathbf{H_{rxf}}$is the receiver height correction factorin dB (-2.8dB for portable MS and 2.5dB for CAB radios) [33]

$$\boldsymbol{\alpha}_{(\mathbf{Hr})} = (1.1 \times \log f) \times H_r - 1.56 \log f - 0.8 \quad [34] \tag{4.17a}$$

$$\mathbf{A = 10\log_{10}\left(\frac{4\pi f d_0}{c}\right)} \tag{4.17b}$$

$$c = 3 \times 10^8\ \text{m/s}$$

Where, d_o is a reference distance most of the time 100m [3].

$$X_f \text{ is a correction for fewquencies above 2Ghz} = 6 \times \log_{10}(\frac{f}{2000}) \tag{4.18}$$

$$X_m \text{ is correction for receiving antenna terrain C} = -20\log_{10}(\frac{f}{2000}) \tag{4.19}$$

$$X_m \text{ is correction for receiving antenna terrain A and B} = -10\log_{10}(\frac{f}{2000}) \tag{4.20}$$

$$\gamma \text{ is path loss exponent} = a - b \times H_b + \frac{c}{H_b} \tag{4.21}$$

The constant parameters a, b, c and S are terrain type dependent and their value is tabulated in (table 4-8) below.

Table 4-8: Erceg model parameter values for different types of terrains [35]

Parameter	Terrain Category		
	A (Hilly/Moderate to heavy tree density)	**B** (Hilly/light tree density or flat/moderate to heavy tree density)	**C** (Flat/light tree density)
A	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.0050
c (m)	12.6	17.1	20.0
S	10.6	9.6	8.2

Erceg model was adopted by the 802.16 group for fixed WiMax, suited for fixed wireless applications [36]. The model consists of base model and extended model.

4.2.2 Comparison of the Propagation Models

For the case study, choosing one appropriate propagation model is mandatory and evaluating all the models at the given parameters for the case study will provide us the better propagation model.

Table 4-9: Parameter values used in the case study (Addis Ababa –Djibouti railway route)

Parameter	**Value**	**Remark**
f (Mhz)	850	
H_b(m)	35	
H_m(m)	1.5	
$\alpha(H_m)$	0	Almost zero for fast moving trains
Terrain type	B and C	Due to geographical nature of the route

Okumura – Hata is the modified form of Okumura model for ease, which makes easy to implement [37]. Moreover, the SUI propagation model is not specifically suitable for the frequency range of the case study as it is suitable for microwave frequency range.

Hence, comparison of the two empirical models (Okumura-Hata and COST 231) using the MATLAB simulation software for the suburban environment (worst case) will be analyzed as shown in figure (4-4).

The second comparative parameter for the case study is the impact of change of UE (MS) antenna height in the system. This thesis assumed value of **1.5m** UE antenna height. However, the user equipments of mobile station may not all be 1.5m. The usability of already existing equipments in a newly designed system is one best cost consideration of engineering.

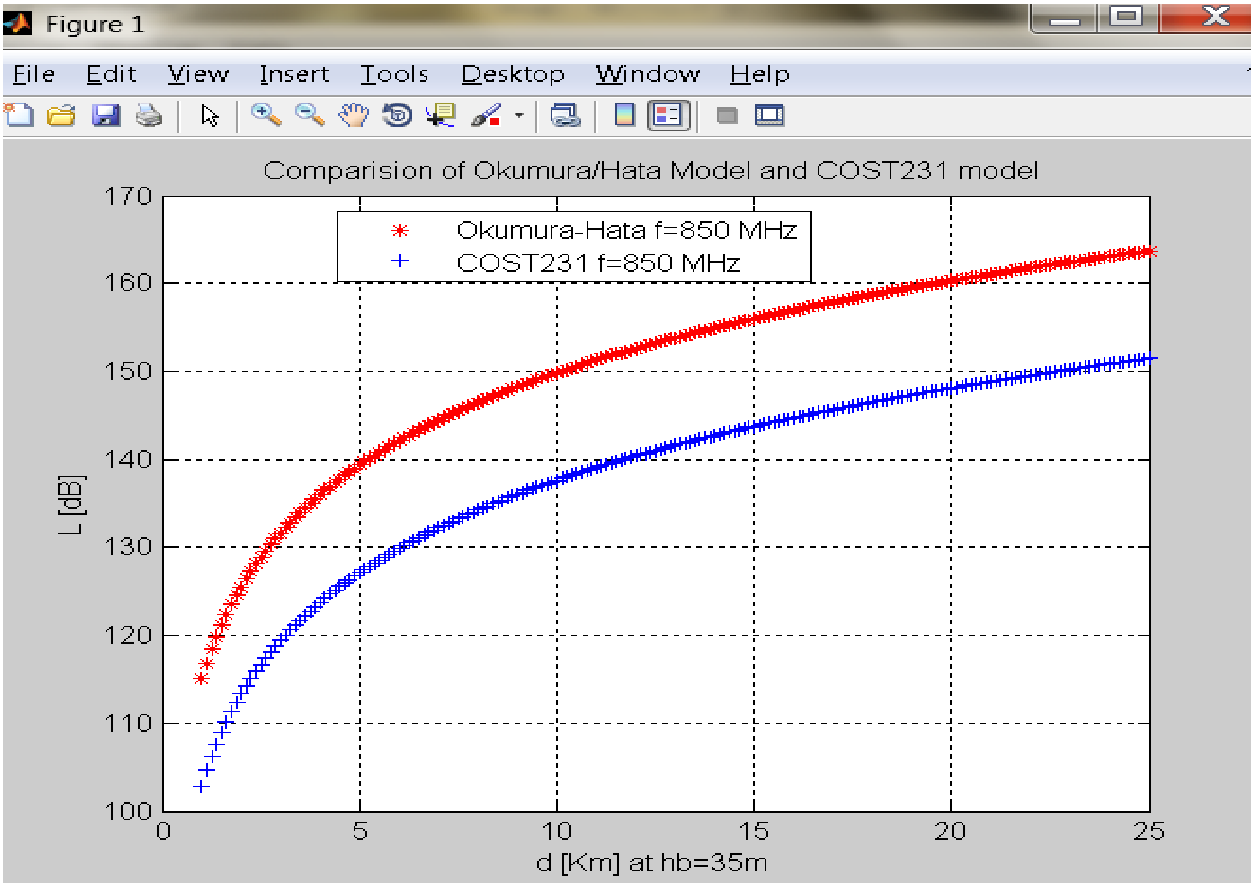


Figure 4-4: Comparison of Okumura-Hatta and COST 231 for coverage distance

From the graph, it is clear that Okumura –Hatta has higher loss than COST 231 model for the same distance coverage. The graph of Cost 231 model gives a very small loss which yields a very large coverage area. For WCDMA cell coverage should be optimized for maximum capacity. Considering the worst case (high loss or less coverage) for the design increases the quality of coverage and uses to optimize the capacity easily.

Assuming the height of antenna varying from 0.25m to 3m, the effect of the path loss of the system for the case study at a coverage distance of 1.5Km (a point which always gains food service) is simulated and the result is shown on figure (4-5) below.

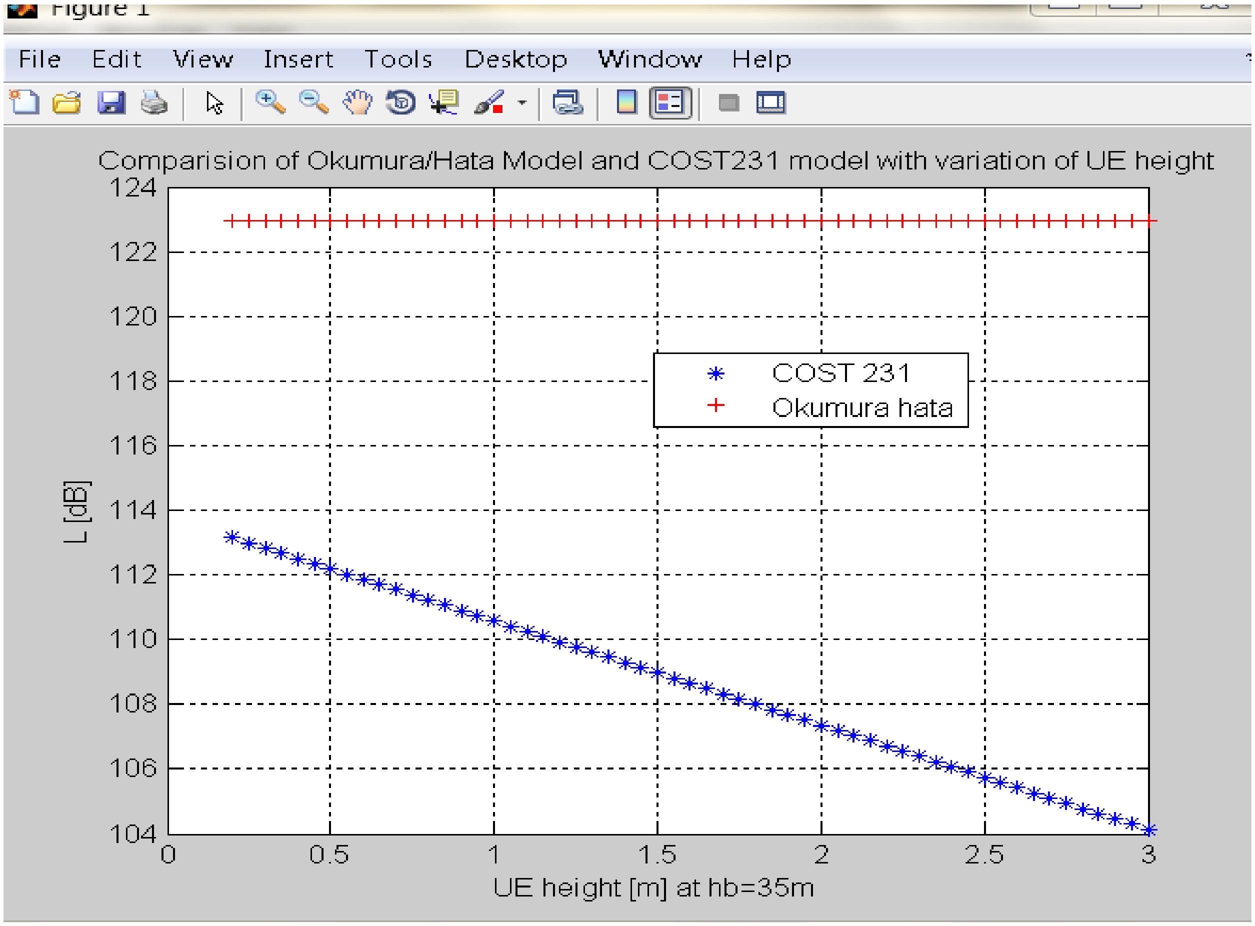


Figure 4-5: Path loss comparison with variation of UE antenna height: for Okumura-Hatta and COST 231 propagation model

From the result, it is observed that the Okumura-Hatta model loss is almost constant (less variant) with the variation of UE antenna height unlike Cost 231 model which varies highly with small UE height variation. This property of Okumura – Hatta is highly recommended since it increases the probability of using existing UE devices which reduces cost. Hence, **Okumura-Hata** path loss propagation model is chosen for this thesis.

4.2.3 Okumura-Hata Propagation Model

The Okumura – Hata model is chosen due to reasons mentioned on the above section. The total path loss is dependent on the nature of the environment. The total path loss for urban area is given in equation (4.21) below and is called as a basic path loss equations in which all the other natures of area (sub urban and rural, flat) are driven from it as referred to as ECC-33 model.

I. Urban area

$$P_l(U) = 69.55 + 26.16\log_{10} f + [44.9 - 6.55\log_{10} H_b]\log_{10} R - 13.82\log_{10} H_b - \alpha(H_{m)} \qquad (4.22)$$

Where**,**

$\mathbf{P_l(U)}$ **is** the total path loss of an urban area in **dB**

f is the operating frequency in **Mhz**

$\mathbf{H_b}$ is the effective height of node B in **Meteres**

R is the cell raduis in **Km**

$\mathbf{H_m}$ is the mobile anttena height in **Meteres**

$\boldsymbol{\alpha}(\mathbf{H_{m)}}$ is a correction factor for the mobile antenna height and is al; most zero. The equation is given by:

$$\boldsymbol{\alpha(H_m)} = \begin{cases} 3.2\,[\log_{10} 11.75 H_m\,]^2 - 4.97 & for\ Urban\ areas \\ [1.1\log_{10} f - 0.7]H_m - 1.56\log_{10} f - 0.8 & sub\ urban\ and\ rural \end{cases} \qquad (4.23)$$

To show that $\boldsymbol{\alpha(H_m)}$ approaches to zero, substituting the typical frequency (850 MHz) and mobile antenna height (H_m)1.5m.

$$\boldsymbol{\alpha(H_m)} = 3.2[\log_{10} 11.75 * 1.5]^2 - 4.97$$

$$= 4.969 - 4.97$$

$$= \underline{\mathbf{- 0.001\ (for\ urban)}}$$

$$\boldsymbol{\alpha(H_m)} = [1.1\log_{10} 850 - 0.7] * 1.5 - 1.56\ \log_{10} 850 - 0.8$$

$$\mathbf{= 3.78 - 3.7698}$$

=-0.01010 (for sub urban and rural)

Equation (4.22) mentioned above is applied for urban radio signal propagation. The case study mainly covers sub urban and rural areas with flat and open areas as shown below.

II. Sub urban area [3]

$$P_l(SU) = P_l(U) - 2\left[log\left({}^{f}/_{28}\right)\right]^2 - 5.4 \qquad (4.24)$$

Where,

$P_l(SU)$ is the path loss of the sub urban area in dB

$P_l(U)$ is the path loss of urban area in dB taken as a reference

f is the frequency of operation in Mhz

III. For Rural

The rural area is subdivided as open and semi-open areas [19]. Hence, different equations are set.

$$P_l(RsO) = P_l(U) - 4.78 \times [\log_{10} f]^2 + 18.33 \times \log(f) - 35.94 \qquad (4.25)$$

$$P_l(RO) = P_l(U) - 4.78 \times [\log_{10} f]^2 + 18.33 \times \log(f) - 40.94 \qquad (4.26)$$

Where,

$P_l(RsO)$ is the path loss of rural semi − open area

$P_l(RO)$ is the path loss of rural open area

For the case of UMTS/WCDMA, due to the parameters that are unique to WCDMA (mentioned in section 4.1.2 of this thesis) the Okumura-Hata model is modified to [27]:

$$P_l(U) = A + B\log_{10} f - 13.82\ \log_{10} H_b - a(H_m\ ) + (C - 6.55\log_{10} H_b)\log_{10} R \qquad (4.27)$$

Where,

$P_l(U)$: is the path loss in urban area (dB).

f : is the carrier frequency (MHz).

H_b: is the base station antenna height (m).

H_m: is the mobile station antenna height (m).

A = 46.3 dB.

B = 33.9 dB.

C = 44.9 dB.

R = the cell range radius (km).

α (H_m) is a correction factor for the mobile antenna height and have almost zero value as proven in (equation 4.23).

Hence, calculating the cell range for the case study using the proposed propagation model (Okumura-Hata) yields the cell range. Using the allowed propagation loss for cell range parameter calculated in the link budget section, the cell range can be obtained by substituting the parameters in to (equations 4.22, 4.25 and 4.26): Considering the suburban and rural areas for the case study given **H_b 35m [**38**]** and **H_m** 1.5m and chosen frequency of **850** MHz:

- **Urban**

  $P_l(U) = 46.3 + 33.9\log_{10} 850 - \ 13.82\log_{10} 35 - 0 + (44. -6.55\log_{10} 35)\log_{10} R$

  $=\underline{124.27 + 33.8}8\log_{10} R$ **(**4.28**)**

- **Sub urban**

$$P_l(SU) = P_l(U) - 2\left[log\left({}^{f}/_{28}\right)\right]^2 - 5.4$$

Substituting f= 850MHz and the path loss of urban area computed in (equation 4.28) above yields:

$P_l(SU) = \ 124.27 + 33.88\log_{10} R - 9.794\,dB,$ for the case WCDMA

$= \mathbf{114.5 + 33.88\log_{10} R}$ (4.29)

Similarly substituting the values in to (equation 2.25 and 2.26) will yield the path loss of semi-open rural and open rural areas as follow:

- **Semi-Open Rural:**

$$P_l(RsO) = \ P_l(U) - 23.2dB$$

$$= \mathbf{101.1 + 33.88\log_{10} R} \qquad (4.30)$$

Rural Open

$$P_l(RO) = \ P_l(U) - \ 28.26dB$$

$$= \mathbf{96 + 33.88\log_{10} R} \qquad (4.31)$$

4.2.4 Cell Range

In the link budget calculation, the maximum allowable path loss is calculated for two different data rates (12.2 Kbps for voice and 144 Kbps for data) taking recommended, standard and calculated values. Hence, the cell range can be obtained by substituting the values of the path loss in to equations (4.29, 4.30 and 4.31).

Table 4-10: Calculated cell range magnitudes of the case study at 850 MHz frequency

<table>
<tr><td colspan="5">The maximum allowed propagation path loss for 12.2 Kbps voice communication and 144Kbps data communication is 141.87dB and 137.76 dB respectively</td></tr>
<tr><th>Area</th><th>Information (Kbps)</th><th>Cell range (Km)</th><th>Area(Km^2)
(Omni-directional)</th><th>Area(Km^2)
(2 sector)</th></tr>
<tr><td rowspan="2">Urban</td><td>Voice 12.2</td><td>3.31</td><td>28.441</td><td>14.22</td></tr>
<tr><td>Data 144</td><td>2.5</td><td>16.267</td><td>8.133</td></tr>
<tr><td rowspan="2">Sub urban</td><td>Voice 12.2</td><td>6.43</td><td>107.32</td><td>53.66</td></tr>
<tr><td>Data 144</td><td>4.86</td><td>61.389</td><td>30.69</td></tr>
<tr><td rowspan="2">Rural semi-open</td><td>Voice 12.2</td><td>15.97</td><td>663.3</td><td>331.64</td></tr>
<tr><td>Data 144</td><td>12.08</td><td>379.4</td><td>189.7</td></tr>
<tr><td rowspan="2">Rural open</td><td>Voice 12.2</td><td>22.6</td><td>1326.67</td><td>663.34</td></tr>
<tr><td>Data 144</td><td>17.08</td><td>758.83</td><td>379.415</td></tr>
</table>

For the case study coverage design, only rural semi-open and suburban cases at the smallest radius are considered to ensure safe coverage across the route.

Due to scientific reasons including better coverage and uniformity of signal strength at the edge of cell, a hexagonal cell type is recommended for the UMTS cellular network like other networks. The coverage area for one cell in a hexagonal configuration is estimated by:

$$\boldsymbol{A_H = k * R^2} \tag{4.32}$$

Where, R is the maximum cell range, accounting the fact that sectored cells are not hexagonal.

k is a constant accounting for the sectors and its values depends on the number of sectors as shown in table (4-11) [39].

Table 4-11: The cell sector constant values for different cell types [39]

Site Configuration	Omni	6-sectored	3-sectored	2-sectored
Value of **k**	2.6	2.6	1.95	1.3

Hence, for the case study (2-sector), the maximum area of a covered hexagonal area is given by: [39]

$$\boldsymbol{A_H = 1.3\ R^2} \tag{4.33}$$

Where, A_H is the area of the cell in square meter and R is the radius of the cell in meter

For the case of railway, since it is a linear construction following a line, rectangular shaped cell could be a good candidate as an option. Rectangular shapes would be good if the line is a straight line. For the case study, since it has many curves, it will be better to use the hexagonal cell but with two sectors. Hence, for every geographical type, for both the voice and data services are given on (table 4-10) above.

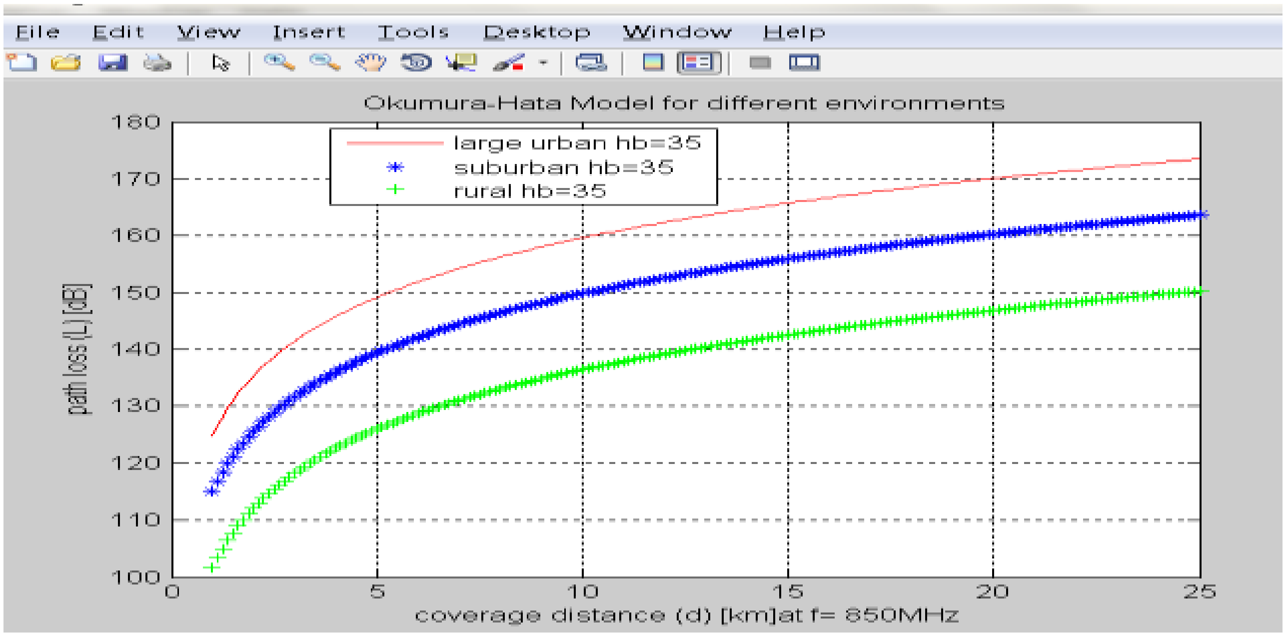


Figure 4-6: Comparison of environmental coverage distance and path loss for loss Okumura-Hata model

The result of simulation in figure 4-6 above proves that coverage area using a single node B is largest in rural and larger in suburban and smallest in urban.

4.2.5 Repeater on Top of Train

For the case of railway signaling, there is a considerable train body loss which depends on the signals' ability to propagate through windows. A way of avoiding further train body attenuation is through the use of repeaters installed on the train as shown in figure 4-7. The two open ended antennas represent repeaters that compensate for the signal attenuation due to train body.

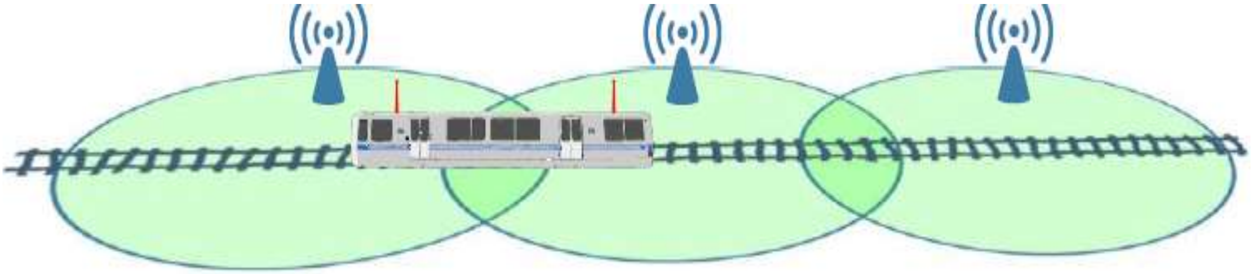


Figure 4-7: Repeats mounted over the train to reduce train body attenuation modified from [9]

4.2.6 Hand Over

The cell range of every environment for the case study is computed and tabulated in (table 4-10). In the case of fast moving trains or any moving UE, the network automatically switches coverage responsibility from one base station to another. Each base-station transition, as well as the switching processor sequence itself, is called handoff/handover. In a properly functioning network, handoff occurs smoothly, without gaps in communications and without confusion about which base station should be dealing with the subscriber. Subscribers to a network need not do anything to make handoff take place, nor should they have to think about the process or about which base station is dealing with the signals at any given moment. Handover may not only occur because of movement but also due to many reasons including [40]:

- When the capacity for connecting new calls of a given cell is used up and an existing or new call from a phone, which is located in an area overlapped by another cell, is transferred to that cell in order to free-up some capacity in the first cell for other users, who can only be connected to that cell.

- In CDMA networks a handover may be induced in order to reduce the interference to a smaller neighboring cell due to the "near-far" effect even when the phone still has an excellent connection to its current cell.
- In non-CDMA networks when the channel used by the phone becomes interfered by another phone using the same channel in a different cell, the call is transferred to a different channel in the same cell or to a different channel in another cell in order to avoid the interference.

The most common type of handover is inter-cell handover, in which handover is made between source cell and target cell (between two different cells). The purpose of inter-cell handover is to maintain the call as the subscriber is moving out of the area covered by the source cell and entering the area of the target cell.

There is a special case handover, in which the source and the target are one and the same cell and only the used channel is changed during the handover. Such a handover is called *intra-cell* handover. The purpose of intra-cell handover is to change one channel, which may be interfered, or fading with a new clearer or less fading channel [40].

4.2.6.1 Types of Handovers

Hard handover: - is a type of handover which is known with optional name break-before-make handover. As its optional name indicates, it is a type of handover in which the channel in the source cell is released and only then the channel in the target cell is engaged. This handover, mostly deployed with GSM system, should be designed in such a way that it has less processing to make it.

Advantage of hard handover

- Hard handover at any moment in time, one call uses only one channel.
- Handover event is indeed very short and usually is not perceptible by the user.
- The phone's hardware does not need to be capable of receiving two or more channels in parallel, which makes it cheaper and simpler.

Disadvantage of hard handover

- If a handover fails the call may be temporarily disrupted or even terminated abnormally.

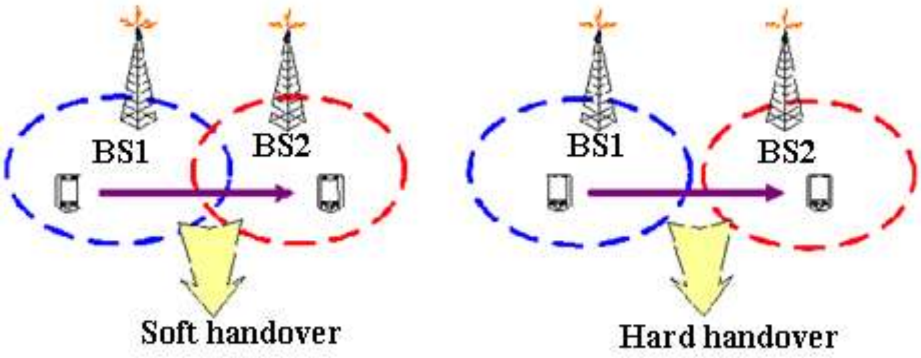


Figure 4-8: Inter –cell hand off strategies for two neighboring cell [40]

Soft handover: - is one in which the channel in the source cell is retained and used for a while in parallel with the channel in the target cell. In this case the connection to the target is established before the connection to the source is broken, hence this handover is called make-before-break. Soft handovers may involve using connections to more than two cells: connections to three, four or more cells can be maintained by one phone at the same time. When a call is in a state of soft handover, the signal of the best of all used channels can be used for the call at a given moment or all the signals can be combined to produce a clearer copy of the signal. Producing clearer copy of the signal is advantageous and when such combining is performed both in the downlink) and the uplink), the handover is termed as **softer**. Softer handovers are possible when the cells involved in the handovers have a single cell site.

Advantages of soft handover

- Less chance to terminate calls abnormally due to its handover method on which connection to the source cell is broken only when a reliable connection to the target cell has been established. The call could only fail if all of the channels are interfered or fade at the same time. However, due to the property; fading and interference in different channels are unrelated and therefore the probability of them taking place at the same moment in all channels is very low, it is almost no occurrence of abnormal call termination in soft handoff strategy. Hence, high reliability of communication.
- Theoretically, soft handovers are possible in any technology, analog or digital.

Disadvantage of soft handover

- High cost of more complex hardware in the phone, which must be capable of processing several channels in parallel.
- Use of several channels in the network to support just a single call. This reduces the number of remaining free channels and thus reduces the capacity of the network.

CDMA based networks should use soft handovers due to the fact that without soft handovers CDMA networks may suffer from substantial interference arising due to the so-called near-far effect [40].

In CDMA systems, when the phone in soft or softer handover is connected to several cells simultaneously, it processes the received in parallel signals using a **rake receiver**. Each signal is processed by a module called **rake finger**. A usual design of a rake receiver in mobile phones includes three or more rake fingers used in soft handover state for processing signals from as many cells and one additional finger used to search for signals from other cells. The set of cells, whose signals are used during a soft handover, is referred to as the *active set.*

For the case of railway system considered in this thesis, it is better to use the ***soft handover***. Hence, the system parameters, equipments to be installed, network system to be deployed should take the soft handover mechanism in consideration

4.2.7 Types of Node B antenna

An antenna is a name given to a piece of conductor that can radiate/receive radio signals up to more complex directional consisting array of elements. The most common way of dividing type of antenna is on their direction of signal radiation; Omni directional and directional antennas.

For our case study, since the network is designed for railway route (guided path), antennas with high gain and narrow beams are required as in GSM-R networks [3]. Hence, a two sector **directional antenna (beam antenna)** which radiates greater power in the two directions is recommended for this study. Even though, a two sector antenna is enough for the case study, in cases where stations or marshaling yards are far from the line, a three sector antenna around stations is recommended to have better coverage.

4.2.7.1 Antenna Tilt and Azimuth

Antenna tilt: The tilt represents the inclination or angle of the antenna to its axis which is used when we want to reduce interference and/or coverage in some specific areas, having each cell to meet only its designed area. There are two possible types of Tilt (which can be applied together): the electrical Tilt and Mechanical Tilt [41]. Tilt can be down tilt or up tilt. The most common type of tilt is down tilt, which is discussed as tilt in this study.

The mechanical tilt is very easy to be understood: tilting the antenna, through specific accessories on its bracket, without changing the phase of the input signal, the diagram (and consequently the signal propagation directions) is modified and for the electrical tilt, the modification of the diagram is obtained by changing the characteristics of signal phase of each element of the antenna, as seen below.

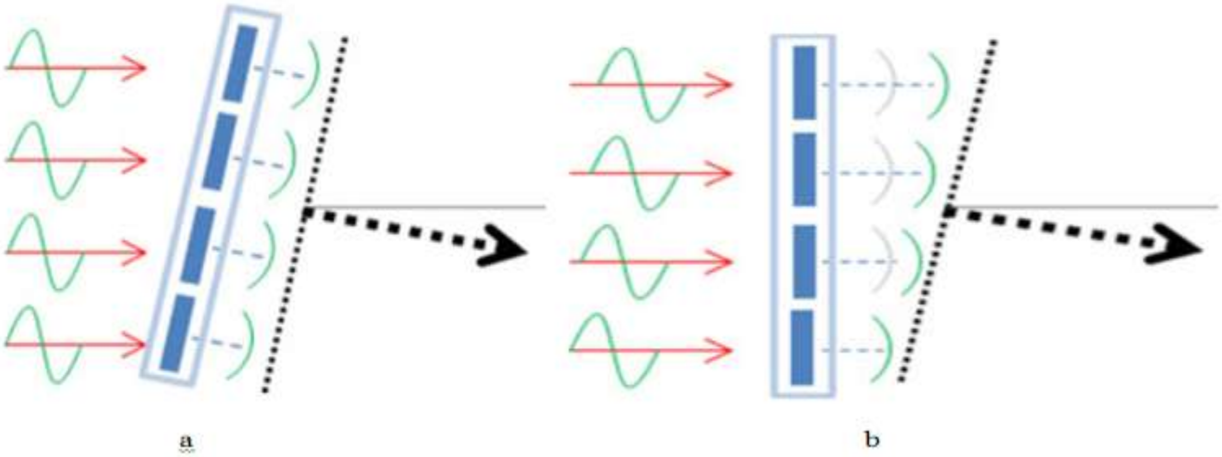


Figure 4-9: Types of antenna tilts: a) Mechanical and b) Electrical [41]

When using mechanical tilt, remember that the horizontal beam-width is wider to the antenna sides, which can represent a problem in C/I ratio in the coverage of neighboring cells. There's not a 'rule', or default value for all the tilts of a network. But considering the most values found in field, reasonable values are: [41]

- 15 dBi gain: default tilt between 7 and 8 degrees (being 8 degrees to smaller cells).
- 18 dBi gain: default tilt between 3.5 and 4 degrees (again, being 4 degrees to smaller cells).

The default tilt is slightly larger in smaller cells because the cells are in dense areas, and a slightly smaller coverage in which loss won't have as much effect as in larger cells [41]. And in cases of very small cells, the tilt is practically mandatory – otherwise we run the risk of creating very poor coverage areas on its edges.

It is easier to control a network when all cells have approximately the same value on almost all antennas: with a small value or even without tilt applied to all cells, we have an almost negligible coverage loss, and a good C/I level.

A good tilts choice maintains network interference levels under control, and consequently provides best overall results. The application of tilt always results in a loss of coverage, but what one should always bear in mind is whether the reduced coverage should be there or not.

For the case study a mechanical tilt is chosen at the simulation section. For simplicity a typical mechanical tilt value of $\mathbf{4^o}$ for suburban and $\mathbf{1^o}$ for rural is taken at normal condition. The tilt value is modified in cases of curves considering the nature of the node B site location.

Azimuth: Azimuth is the angle formed between a reference direction and a line from the observer to a point of interest projected on the same plane measured in degree ($^{\mathbf{o}}$) [42]. The concept of azimuth is used in navigation, mapping, astronomy, Engineering, mapping, mining and artillery. The azimuth angle is like a compass direction with North = 0° and South = 180° [43]. Hence, for the case study, a mechanical azimuth of 0^o is used since it is on the north direction. However, on optimization, a mechanical azimuth that can give best signal level will be used.

4.3 Load Factor

Estimating the amount of supported traffic by each base station is the second phase of dimensioning. WCDMA system is interference limited since the ruse factor is 1. Hence, the amount of interference and capacity must be estimated.

4.3.1 Uplink Load Factor

In theory, the spectral efficiency of WCDMA cell is obtained from the uplink load factor equation given by: [6]

$$\eta_{ul} = \sum_{j=1}^{N} L_j \tag{4.32}$$

Where,

N is the number of users per cell

$\mathbf{L_j}$ is the load factor of each connection

The load factor of each connection is derived from the definition of E_b/N_o which can be written as:

$$({E_b}/{N_o})j = \ processing\ gain\ of\ user\ j\ \times \frac{signal\ of\ user\ j}{interference\ from\ other\ user}$$

$$({E_b}/{N_o})j = \frac{W}{V_j R_j} \times \frac{P_j}{I - P_j} \tag{4.34}$$

After some derivations done in [28], the uplink load factor is modified to:

$$\eta_{UL} = (\mathbf{1} + \boldsymbol{i}) \sum_{j=1}^{N} L_j = (\mathbf{1} + \boldsymbol{i}\ ) \sum_{\boldsymbol{j}=\mathbf{1}}^{\boldsymbol{N}} \frac{\mathbf{1}}{\mathbf{1}+\frac{\boldsymbol{W}}{\left(\frac{\boldsymbol{E_b}}{\boldsymbol{N_o}}\right)_{\cdot\boldsymbol{j}}*\boldsymbol{R_j}*\boldsymbol{V_j}}} \tag{4.35}$$

Where,

$\eta_{\mathbf{UL}}$ is the uplink load factor

N is number of users per cell

$\frac{\mathbf{E_b}}{\mathbf{N_o}}$ is the signal energy per bit divided by noise spectral density that is required to meet a predefined block error rate.

W CDMA chip rate

$\mathbf{R_j}$ bit rate of user j

$\mathbf{V_j}$ is activity factor for user j and is 0.67 both for voice and data

i is the other cell to own cell interference factor given by:

$$\mathrm{i} = \frac{\text{other cell interference}}{\text{own cell interference}} \tag{4.36}$$

The amount of noise rise over thermal noise due to interference can be predicted from the load equation (4.34).

$$\boldsymbol{N_r} = \frac{\mathbf{1}}{(\mathbf{1} - \eta_{UL})} = -\mathbf{10}\,\mathbf{log_{10}}(\mathbf{1} - \eta_{UL})\ (\boldsymbol{dB}) \tag{4.37}$$

The load equation is commonly used to make a semi-analytical prediction of the ***average capacity*** of a WCDMA cell, without going into system-level capacity simulations. This load equation can be used for the purpose of predicting cell capacity and planning ***noise rise*** in the dimensioning process. Higher noise rise means higher capacity and smaller footprint, a lower noise rise means smaller capacity and bigger footprint [44].

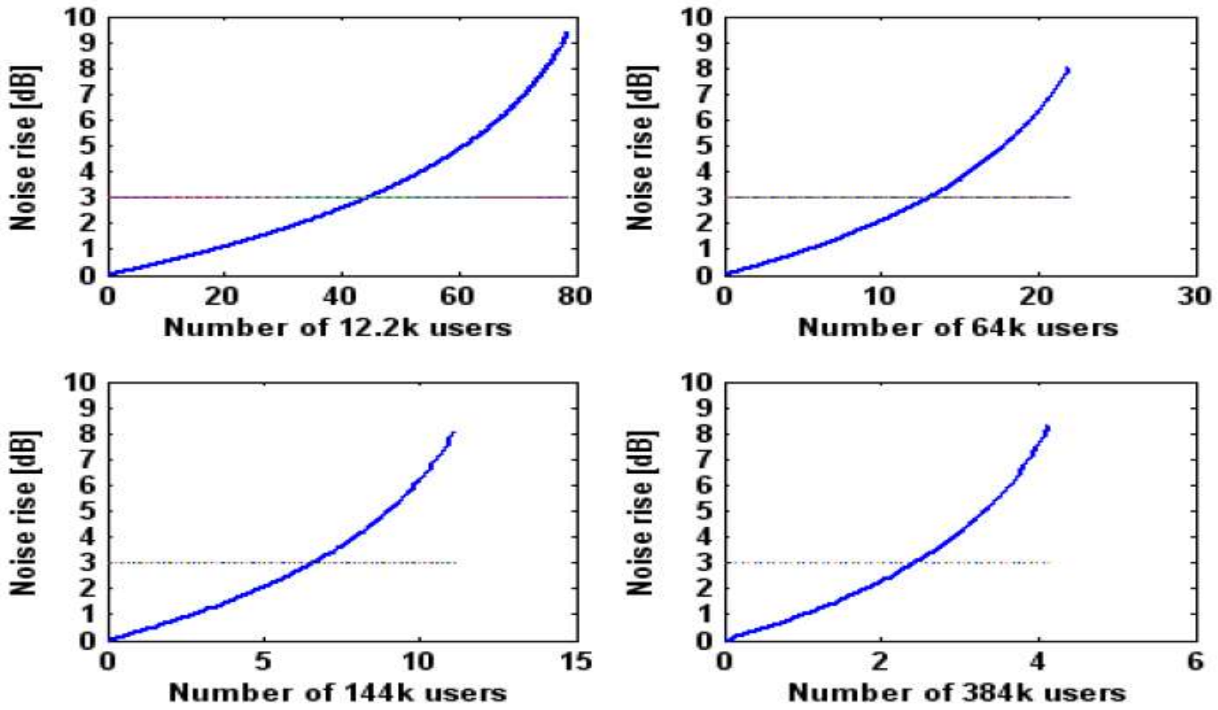


Figure 4-10: Number of uses Vs noise for different data rates [27]

As shown in the figure, the number of users is increasing for less data rates at a given noise raise value. For case of voice only service network, where all users have a low bit rate of R, the load equation can be simplified in to equation (4.38).

$$\boldsymbol{\eta}_{UL} = \frac{E_b/N_o}{W/R}\, N.v.(1+i) \tag{4.38}$$

Where v is activity factor of a user

The noise rise increases with increasing throughput which is a function of the number of simultaneous users.

$$Th = N \times R \ \times (1 - BLER) \tag{4.39}$$

Where, BLER is the block error bit and have a recommended value of 10% for voice and 1% data communication [27].

From the relation of throughput (Eq.4.38) and noise raise (Eq. 4.37), the noise raise will exponentially increase with increasing throughput or number of users. For example, taking a data rate of 12.2Kbps and simulating the graph using MATLAB will yield as shown in figure 4-11.

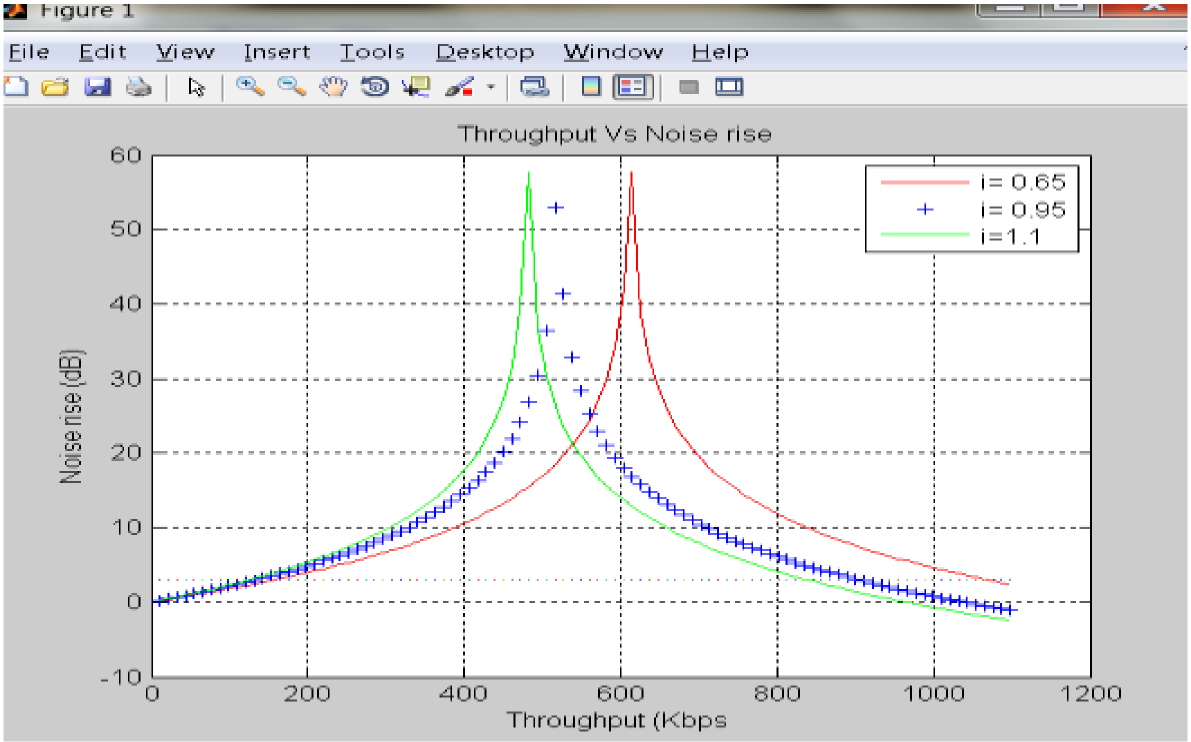


Figure 4-11: Throughput Vs noise rise of 12.2Kbps voice communication for various i values

For the case study a noise rise of 3dB is considered and a throughput of 167 Kbps can be achieved for voice service at i =0.65 as shown in figure 4-11. From the graph it is visible that the throughput is reduced as the value of interference level increases for a given noise raise value. For all interference factor values there is a collapse point where the throughput starts to fall. This point indicates the system reaches its pole (maximum) capacity, which above this capacity the system enters to unstable state.

4.3.2 Uplink Cell Capacity Estimation

Pole capacity: - is the theoretical maximum capacity of the system. In **WCDMA**, this capacity is only theoretical since, once reached, the system goes in to an instable state that leads to its collapse. However it is still a reference for expressing the load. It can be estimated using the simplified standard uplink capacity equation [6].

$$\boldsymbol{N_{pole}} = \frac{\boldsymbol{W/R}}{\boldsymbol{E_b/N_o} * \boldsymbol{v} * (\boldsymbol{1} + \boldsymbol{\alpha})} \qquad (4.40)$$

Where,

α is orthognal factor and v is activity factor of a user

If the number of Subscribers is **Ns** then for a single CDMA cell, the number of users will be:

$$N_s = 1 + \left(\frac{W/R}{Eb/No} - \frac{\eta}{S}\right)\frac{1}{\alpha} \qquad (4.41)$$

Where, **Ns** =total number of users, **W**=chip rate, **R**= base band information bit rate, $\mathbf{E_b/N_o}$=Energy per bit to noise power spectral density ratio, $\boldsymbol{\eta}$ = background thermal noise, **S** = signal power.

$$\mathrm{S} = \mathrm{S}_1 - \mathrm{P(d)} - \text{Shadowing Fading} \qquad (4.42)$$

Where, $\mathbf{S_1}$ is UE power and **P(d)** is propagation loss.

The above uplink capacity equation (4.41) should be modified to be applied in practical application by adding additional considerations that yields a reliable UMTS uplink capacity. Those include: multiple cells or intra-cell interference (β), cell sectoring (D), soft handover factor (H), Array antenna gain (A_g). Hence, the capacity of WCDMA in UMTS gives:

$$\boldsymbol{N_s} = \boldsymbol{1} + \left(\frac{W/R}{E_b/N_o} - \frac{\boldsymbol{\eta}}{\boldsymbol{S}}\right)\frac{\boldsymbol{1}}{(\boldsymbol{1}+\beta)\boldsymbol{\alpha}}\boldsymbol{H} * \boldsymbol{A_g} \qquad (4.43)$$

Equation (4.41) is a more complex equation which is applied in practical design. The flat estimation of UEs per NB can be obtained from equation (4.40).

$$\boldsymbol{\eta_{ul}} = \frac{\boldsymbol{E_b/N_o}}{\boldsymbol{W/R}}\boldsymbol{N} * \boldsymbol{v} * (\boldsymbol{1} + \boldsymbol{\alpha}) \qquad (4.44a)$$

$$N_{user} = N_{pole} * \boldsymbol{\eta} \qquad (4.44b)$$

For the case study taking **12.2Kbps** for voice communication taking a scientifically assumed value of loading factor = 75%, $\boldsymbol{E_b/N_o}$ **= 5dB = 3.24W,** $v = 0.6\ for\ macro\ cellular$

$W/R = \frac{3.84*10^6}{12.2*10^3} = 314.75,$ for voice only communication

$$1 + \alpha = 1 + 0.6 = 1.6$$

Using equations (4.44a) and (4.44b)

$$0.75 = \frac{\mathbf{3.24*0.6*(1+0.6)}}{\mathbf{314.75}} * \mathbf{N}$$

N=75.89 = 76

Hence, in the case of UL limited system, the maximum numbers of users served voice only service by a single NB having single carrier is 76.

Since the system supports mixed traffic, the maximum number of data users should also be estimated. In [10], typical maximum uplink pole capacity of packet switched data is calculated at 120Km/hr with fast fading and a value of 8.11 is given to 144Kbps packet access for three sector antenna. With flat ratio assumption for two sectors a value of $\frac{2}{3} \times 8.11 = 5.34$ is the maximum pole capacity at 100% load. In this case 75% loading is assumed and the value of the pole capacity will be 4. Hence for two sectors, the number of 144kbps users with fast fading at a speed of 120km/hr is: $2 \times 4 = 8$ users.

This is theoretical uplink capacity. The number of users may increase or decrease as per the type of service and the load factor. Theoretically, for an uplink limited system the total number of users that can be connected to a single node B is 84 (76 voice and 8 data).

4.3.3 Downlink Load Factor

The downlink load factor is the same as uplink load factor except it uses some different parameters. It is given by [27, 29]:

$$\eta_{DL} = \sum_{j=1}^{N} \boldsymbol{v_j} \times \frac{\boldsymbol{E_b}/\boldsymbol{N_o}}{\boldsymbol{W}/\boldsymbol{R_j}} \times [(\boldsymbol{1} - \boldsymbol{\alpha_j}) + \boldsymbol{i_j} \tag{4.45}$$

Where**,**

$\boldsymbol{\alpha_j}$ is an orthogonal factor typically used in the downlink and have a value betwenn 0.4 upto 0.9

$\boldsymbol{v_j}$ is the activity factor of user j

$\mathbf{i_j}$ is the other cell to own cell interference factor and mainly depemds on the user location.

hence, it has different value for each user j

We use $\boldsymbol{\alpha_j}$ because WCDMA employs orthogonal codes in the downlink to separate users, and without any multipath propagation the orthogonality remains when the base station signal is received by the mobile. The downlink load factor ($\boldsymbol{\eta_{DL}}$) exhibits very similar behavior to the uplink load factor $\boldsymbol{\eta_{UL}}$, in the sense that when approaching unity, the system reaches its pole capacity and the noise rise over thermal goes to infinity.

For downlink dimensioning, estimating the total amount of base station transmission power required is a critical task. This should be based on the average transmission power for the user, not the maximum transmission power for the cell edge shown by the link budget [45].

Mathematically, the total base station transmission power can be expressed by the following equation [28]:

$$NB_{Txp} = \frac{N_{rf} \times W \times \overline{L}}{1 - \overline{\eta_{DL}}.} \times \sum_{j=1}^{N} v_j \frac{E_b/N_o}{W/R_j} \tag{4.46}$$

Where,

$\mathrm{NB_{Txp}}$ is the node Bs higest transmit power

$\overline{\mathrm{L}}$ is the average path loss (minimum power level required by user)

$\mathrm{N_{rf}}$ is the noise spectral density of the UE receiver front end and can be obtained by:

$$\mathrm{N_{rf}} = -174\mathrm{dBm} + \mathrm{N_F}$$

$\mathrm{N_F}$ is the noise figure with typical value

In WCDMA, the exact DL capacity can't be calculated independent of coverage. However, nearby estimations can be done and the exact optimized capacity can be obtained in detailed planning of the network. Estimated capacity can be calculated based on capacity per area and capacity per population density.

4.3.4 Downlink Capacity

In WCDMA, capacity can't exactly compute without coverage unlike GSM. This thesis mainly concerns on safe coverage and downlink capacity as of the route for future operation. An estimation of maximum capacity can be done by taking some assumptions. In this thesis two maximum capacity estimation methods from studies are evaluated for the case study: The capacity per area and capacity in terms of density of users. The first case is mostly used in case of uniformly distributed users.

4.3.4.1 DL Capacity per Area

In WCDMA, the challenging property is that; capacity can't be designed independent of coverage. However, the maximum amount of data over a given area can be estimated. For macro-cell WCDMA cell, the maximum capacity per site (cell) per carrier is **3Mbps** assuming three sector [27]. This shows that each optimized sector has a maximum data of **1Mbps**.

For the case study, a two sector antenna is chosen. Hence, a total of **2Mbps** per site per carrier is attained. Only suburban and rural areas are considered with their radius and areas calculated and tabulated in table (4-10).

To ensure the assumption of good coverage, considering the shortest radiuses and only two cases of sub urban and rural semi open (**4.86 Km** for suburban and 12**.08 Km** for rural) with area of 30.69 Km^2 and 189.7 Km^2 respectively optimizes the number of NB per Km^2. During the detail coverage design, there will be consideration to the nature of the site where each node B is to be deployed (suburban or rural). Hence, the average area of a cell across the route can be obtained after the right position of the NBs is decided. Theoretically, if there are **M** number of total node Bs across the route, having **H** number of NBs under suburban consideration and **D** number of NBs under the consideration of rural, then the average cell area coverage can be given as:

$$\boldsymbol{A_{av}} = \frac{\boldsymbol{30.69 \times H + 189.7 \times D}}{\boldsymbol{M}} \tag{4.47}$$

In the downlink the coverage depends more on the load than in the uplink. The reason is that in the downlink the maximum transmission power is the same power regardless of the number of users and is shared between the downlink users, while in the uplink each extra user has its own power amplifier. Therefore, even with low load in the downlink, the coverage decreases as a function of the number of users [45].

4.3.4.2 Downlink Capacity of the Mixed Traffic in Terms of Users

The link budget of 12.2Kbps circuit switched and 144Kbps packet switched data is computed. Hence, the coverage design should be optimized for the mixed traffic. The maximum download capacity of 12.2Kbps speech service is 25mErlang per subscriber for 50% activity factor and service of 128Kbps, 250Kbyte/hr with best effort [10].

Due to the reason that WCDMA provides different services at different data rates, the radio network design using this technology requires a multiservice network design. Typical value of mixed downlink maximum capacity at 100% load for a three sector site configuration is 120, 15 and 11 for 12.2Kbps, 64Kbps circuit switched and 128 Kbps packet switching channels respectively [46].

Considering the simplest manner (by dividing the number of channels per sector) for our case (2 sector) 80 channels of 12.2Kbps and 12 users (assumed at worst case) for 144Kbps simultaneous users are supported by a single cell. In the link budget, at the edge of the cell only 75% coverage is considered. Hence, the supported relative load is:

$$= 0.75 \times 80 = 60\ channels.$$

Referring to Erlang B table, with assumed grade of service (GoS) of 2% for 60 channels is 42.2E. Hence, the maximum estimated number of simultaneous speech users per cell is:

$$= \frac{42.2E}{0.025E} = 1688$$

The result shows that approximately a maximum of 1688 users at a rate of 12.2Kbps speech traffic can access the mixed network. For the case of cells that with dense users (around stations and control rooms for our case), increasing the carrier per call in the cell will increase the number of users. For example, using 4 carriers per call will yield $4 \times 1688 = \mathbf{6752}$ users [46].

For the case of 144Kbps packet switched data, the total data per sector per hour should be estimated. Technically, one sector can support 26.3E of data with 35 channels (GoS of 2%) [46]. Hence, the served traffic is: $26.3E \times 0.98 = \mathbf{25.77E}$. So the load available for packet traffic with system coverage of 75% is: [16] = $coverage - \frac{served\ traffc}{N\ of\ other\ service\ at\ full\ load}$ (4.48)

Where, N is number of users. Hence,

$$0.75 - \frac{25.77}{80} = \mathbf{0.43}$$

Hence, the downlink can support, $= 0.43 \times 144Kbps \times \frac{3600}{8} = 27.211\ {}^{Mbyte}/{}_{sector}/{}_{hr}$

For the case study, there will be a total of $2\ sector \times 27.211\ {}^{Mbyte}/{}_{sector}/{}_{hr} = \mathbf{54.422\ Mbyte/hr}$

Taking a flat assumption from [10] of 260 Kbyte/hr data for single subscriber, the total amount of subscribers is $= \frac{54.422Mbyte}{260Kbyte} \cong 209$

In case of higher data rate requirement (around stations and control rooms), increasing the number of carrier will upgrade it. For example, with 4 carriers per subscriber, a total of **217.688 Mbyte**/hr can be achieved. This can serve 836 peoples per cell. This is a flat assumption that every user uses the same data rate. However, in practical deployment more data rate requirements may yield to reduce the number of users. But it is true that there is an estimated maximum data of 54.422**Mbyte/cell/hour**. Having a total of **48.5** sites (NBs) across the route, there will be a maximum of **81868** voice users and **2639.467** Mbytes/hour (**10151.78** users per hour) voice and data service respectively with a given single carrier. In cases that need higher data rate increasing the carrier is a solution [10]. Hence, a total of above 92020 mixed traffic subscribers per hour can be supported throughout the route.

4.4 Design Redundancy for Reliability

The need for radio communications in the railway environment should be very high availability and quality 100% of the time, everywhere and at all speeds [47].

For high availability, the dimensioning rules are:

- Core system should be in well protected sites with geographical redundancy.
- Duplicated transmission in physical separated routs to all Node Bs (NBs)
- Duplicated transceiver (TRX) in all NBs.
- Duplicated radio network controllers (RNCs)
- Duplicated antenna system.
- Having uninterrupted power supply (UPS) for at least few hours for reliability purpose
- Power supply on core sites is protected with duplicated UPS.

To increase reliability redenduncy is recommended all over the sub systems of the network.

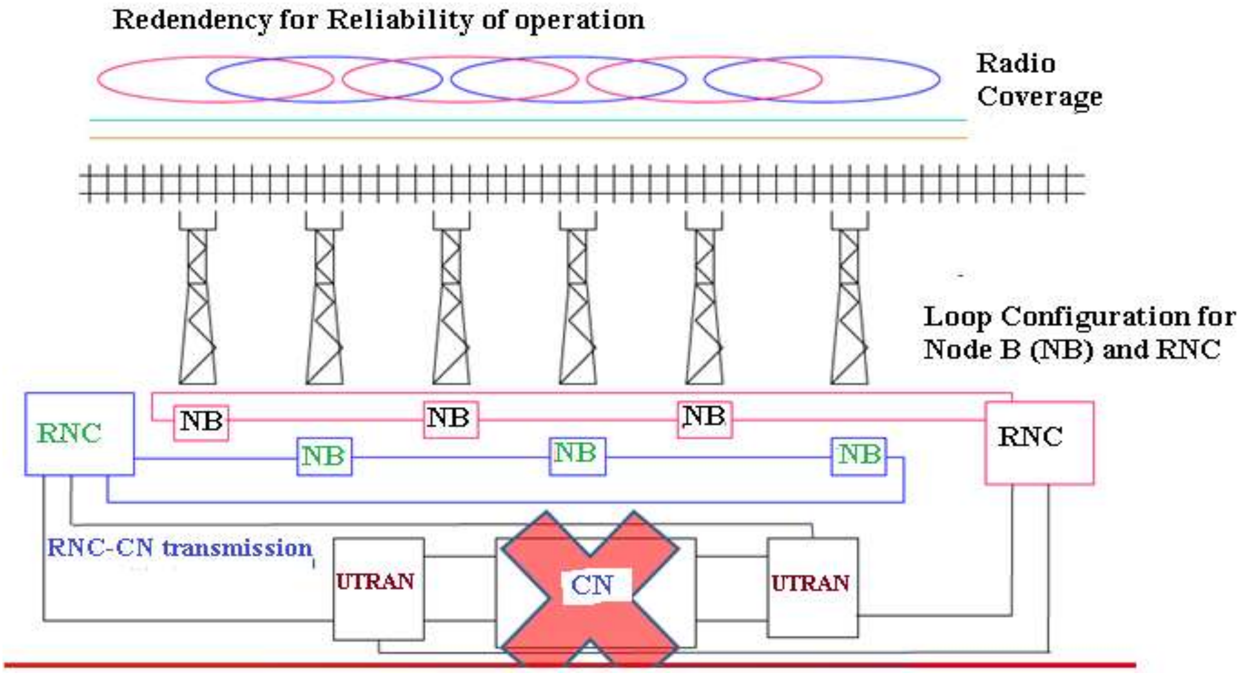


Figure 4-12: Redundancy of UMTS-R subsystem to increase reliability edited from [47]

For the case study those two networks can be operated by two independent operators (ethio-telecom and Djibouti telecom) or the same operator with independent UTRAN and RNC. The matter which operator will operate doesn't matter, as long as reliability is maintained. The block diagram of the redundant UMTS-R radio coverage and capacity system for the case study is shown in figure 4-12 below.

Where,

MSC-Eth and RNC-Eth are the main system Mobile Switching Center (MSC) and Radio Network Controller (RNC) of system respectively.

MSC-Dji and RNC-Dji is the backup (redundant) MSC and RNC respectively.

The number of RNC may increase beyond one in every system.

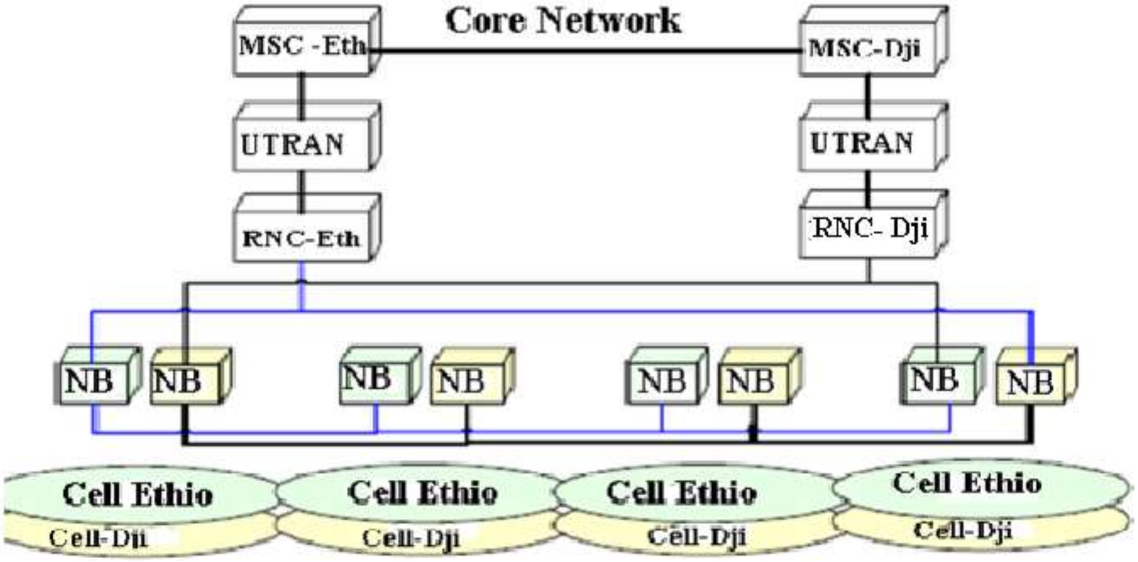


Figure 4-13: Redundancy of UMTS-R subsystem for Addis Ababa-Djibouti route modified from [46]

Cell Ethio is to mean the first cells that will operate after the deployment of the UMTS-R system under healthy condition and **cell-Dji** are redundant cells that can operate in case of failure or vice versa.

This thesis designs the redundant NBs which can serve the Addis Ababa – Djibouti railway route considering the nature of geographical location of NB sites. To create a full redundant system, redundant UTRAN, RNC and core network of the route is a work to extend in the future.

4.4.1 Quantitative Analysis of System Reliability and Safety

Reliability (safety) can be expressed quantitatively with some parameters that describe the occurrence of failure and its avoidance. The most known parameters are defined in [48] as follows:

Mean Time Between Failures (MTBF) is a reliability term used to provide the amount of failures per million hours for a product. MTBF is more important for industries and integrators than for consumers [48]. For the case study, the Ethiopian railway cooperation and the Djibouti's on the other side should take care of reducing MTBF. Hence, in case of deploying the full system, MTBF of every hardware device that support the UMTS-R system should be considered to ensure safety and reliability.

Mean Time To Repair (MTTR) is the time needed to repair a failed hardware module. In an operational system, repair generally means replacing a failed hardware part. Hardware MTTR could be viewed as mean time to replace at failed hardware module.

Mean Time To Failure (MTTF) is a basic measure of reliability for non-repairable systems. It is the mean time expected until the first failure of a piece of equipment. MTTF is a statistical value and is meant to be the mean over a long period of time and a large number of units.

Failure In Time (FIT) is another way of reporting MTBF. FIT reports the number of expected failures per one billion hours of operation for a device.

There are two ways of predicting reliability: Parts Count Prediction (used to predict the reliability of a product in its early development cycle) and Parts Stress Analysis Prediction (used later in the development cycle, as the product nears production) [48].

MTBF, MTTR, MTTF and **FIT** are reliability terms based on methods and procedures for life cycle predictions for a product [48]. Hence, for the case study, the quantitative value of reliability mainly depends on the life cycle and failure rate of equipments to be used during deployment.

Reliability methods such as MTTR, MTTF and FIT apply to products or to specific components. However, MTBF remains a basic measure of a systems' reliability for most products. MTBF (the expected working hours before failure), is often calculated based on an algorithm [48]. There are a number of ways of expressing reliability, but one commonly used is the MTBF because it is used to measure reliability of even non reliable items unlike to MTTF [49].

The average or more realistic expected service life or MTBF is given by [48, 49]:

$$\boldsymbol{MTBF = \frac{1}{FR_1 + FR_2 + FR_3 + \cdots + FR_n} = \frac{Total\ operating\ time}{Number\ of\ failures}} \tag{4.49}$$

Where, FR is the failure rate of each component of a system up to n component.

4.4.2 Reliability and Safety Verification

As per [50], "reliability is defined as the probability of a system (component) to complete the regulated function under specified functions and in range of prescribed time". To express reliability and safety mathematically, defining a random variable time T (time to failure of the system or component) will yield reliability and safety as follows [50]:

$$\boldsymbol{R(t)} = \begin{cases} \boldsymbol{P(T > t)} & \boldsymbol{t \geq 0} \\ \boldsymbol{0} & \boldsymbol{t < 0} \end{cases} \tag{4.50}$$

Where, R (t) is the reliability of the system or component in need with value of ***R(t) ≥ 0*****.** The value of the reliability at T= 0 is full (**R(0) = 1)** and the value of the reliability as time goes to infinity is zero **(**$\boldsymbol{\lim_{t\to\infty} R(t) = 0}$) **[**50**].**

In analyzing reliability of a complex system, the appropriate reliability should be obtained by modeling the reliability of every component in the system and applying rule of probability [50]. For the case study the exact reliability value will be computed after the detail components system design is completed.

Corresponding to reliability, the uncertainty and the MTTF are given by [50]:

$$\boldsymbol{F(t) = 1 - R(t)} \tag{4.51}$$

Where,

F(t) is the uncertainty and R(t) is the reliability

$$MTTF = \int_0^{+\infty} R(t)dt \tag{4.52}$$

Unlike to reliability, availability and MTTF which concern on the normal work of the system, safety refers to the ability that the system could not generate the dangerous side outputs when the fault occurs [50]. In case of railway there are two important cases to be considered: safety failure state and dangerous failure state which corresponds to probability of safe failure (PSF) and probability of dangerous failure (PDF) respectively. The uncertainty of the system regarding to failure is given by [50]:

$$F(t) = PSF(t) + PDF(t) \tag{4.53}$$

For reliable railway systems the availability and safety availability are different and are given by [50]:

$$A(t) = 1 - F(t) = 1 - [PSF(t) + PDF(t)] \tag{4.54}$$

Where A(t) is the system availability and F(t) is the system uncertainty, PSF is the probability of fail safe and PDF is the probability of fail dangerous.

$$S(t) = 1 - PFD(t) \tag{4.55}$$

Where, S(t) is the system availability

System safety not only depends on failure but also on the system ability to detect the failure [50].

Failure rate (λ) is often used to express the reliability of simple items and components. It is also frequently used to express the reliability of particular functions, for example the dangerous failure rate of a safety system [49]. It is measured in per hour and is given by:

$$\lambda = \frac{\text{Number of failures}}{\text{Total operating time}} \tag{4.56}$$

According to TL900 specification, the MTTR of telecommunication equipment is less than 3 hours. In fact the MTTR of most vendors' equipment is 1 hour [51]. In [51], availability of single network system (considered single Core network, HLR, MSC and UTRAN) availability is calculated to be 99.995% and an interruption time of 26 minutes per year while a dual network system has an availability of 99.999% and interruption time of 0.26 minutes per year with MTBF of 99999 hour. This shows that the dual network increases the availability and mainly the reliability by reducing the interruption time.

4.5 Radio Network Coverage of Tunnel

The Addis Ababa – Djibouti route includes a tunnel of 380m around Awash [3]. It is not expected to receive a wireless network from the already deployed node Bs. Special radiating cables should be installed inside the tunnel by connecting to a repeater at the two ends of the tunnel so that safe operation is held. Figure 4-14 below edited using paint image editor shows a repeater capable of receiving radio signal and transmits to radiating cables installed across the tunnel deployed at the gate of the tunnel.

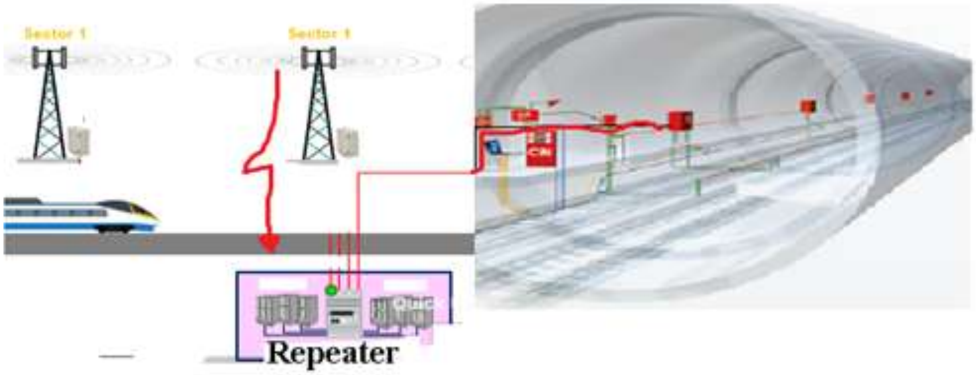


Figure 4-14: Thee radio access coverage of UMTS-R in a tunnel

The repeater should be a smart device and operable at the case study frequency range that can receive a wireless signal and feed to a radiating cable installed inside the tunnel. Radiating cables facilitate radio communication where the usual free space propagation of electromagnetic waves is hampered, undesired or impossible in tunnels and other underground communications in the range of 380 to 2700 MHz [52].

Chapter Five

5. Simulation and Result

5.1 Simulation

5.1.1 Simulation Process

The network coverage simulation is done using Atoll radio network coverage and optimization software. Inter-mediate software's were used to extract the digital map and prepare in the way appropriate for Atoll due to the absence of digital map regarding to the route.

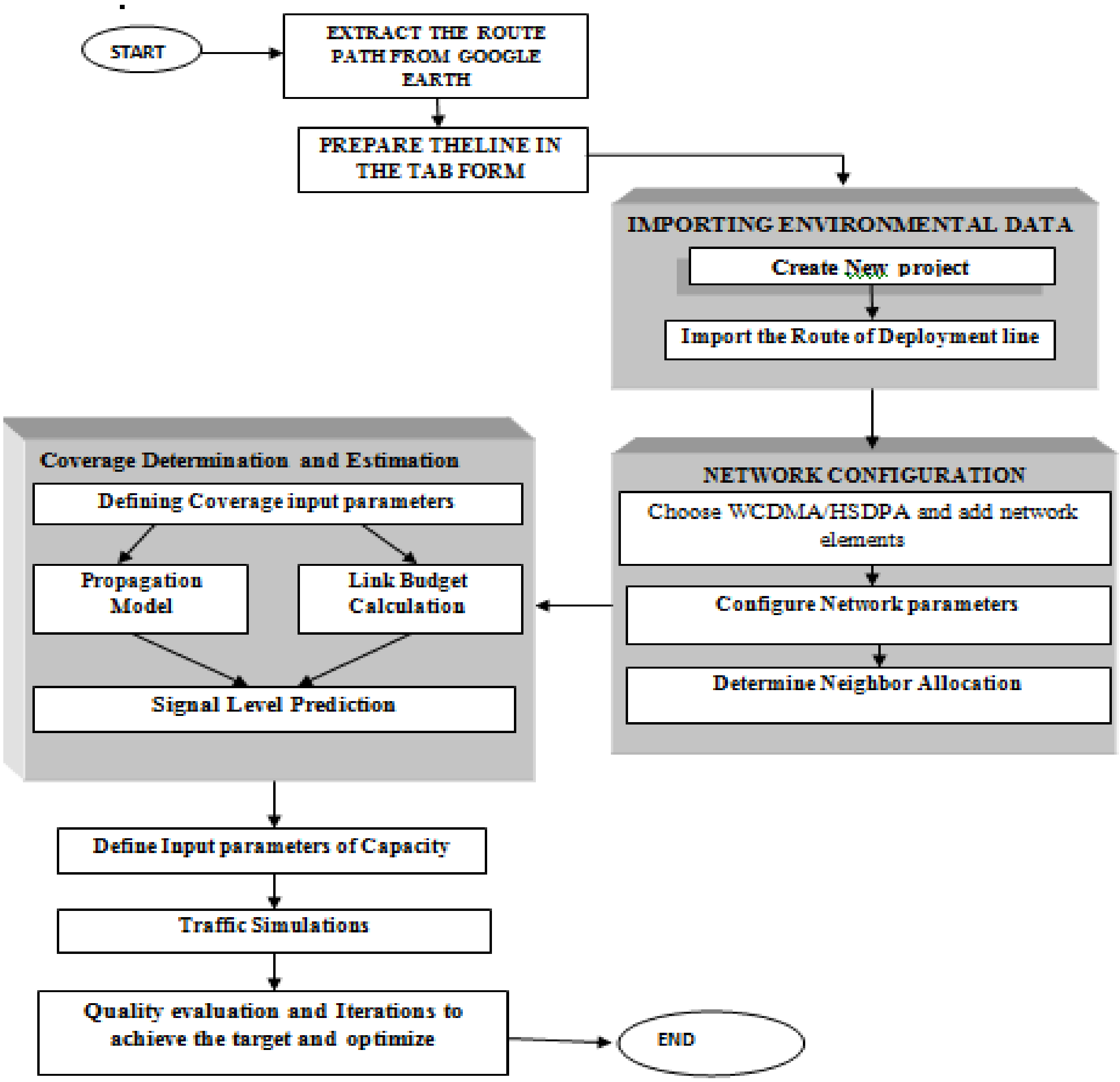


Figure 5-1: Flow chart of UMTS-R simulation process

Figure 5-1 above is the overview, process of simulating result for the case study route. The first step on the design is to create the path on Google earth and is as shown in (figure 5-2) for the case study. This file is saved as KML and prepared to the next task.

Figure 5-2: AA-Djibouti railway route created in Google earth (KML file)

This KML file is changed using ZONUMS online solutions to CAD file and finally to TAB file using MapInfo 7.8 professional software which is the final input map to the Atoll network designing tool.

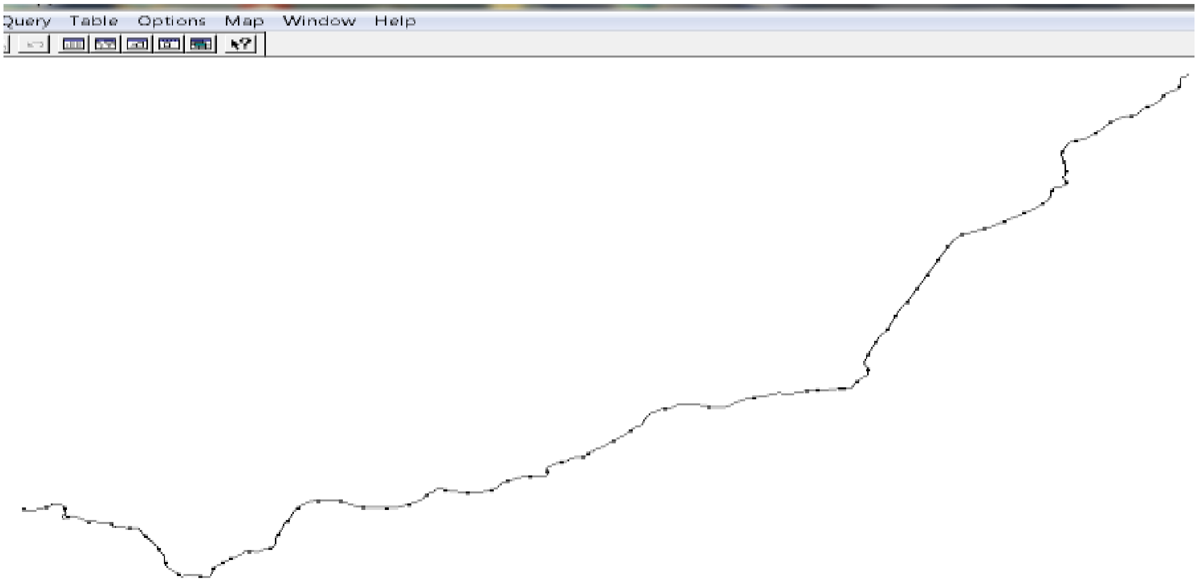


Figure 5-3: AA-Djibouti railway line route prepared as .TAB input for ATOLL simulation

The TAB file shown in figure 5-3, is the final route line used to be imported to the ATOLL software by creating a new project file and choosing a WCDMA/HSDPA network access type. The calculations from link budget (radius and loss) are considered in addition to design considerations regarding the geographical and morphological nature of the Node B site. Only two environmental natures (suburban and rural) are considered. Since this system is designed for the long term (2035), the extension of suburban area is considered.

5.1.2 Radio Resource Management (RRM)

RRM consists of set of algorithms of admission control, power control, handover control and is responsible for providing reasonable operation of the network [4]. The statistical optimization loop is needed to change the limits controlling RRM so that the network operating point is in optimum in terms of capacity and quality. The capacity-quality trade off and interaction of optimization and RRM is illustrated in figure (5-4).

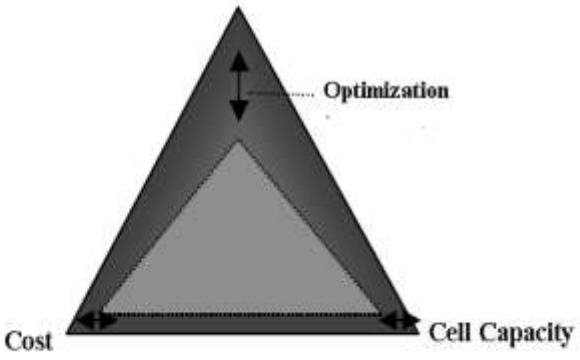


Figure 5-4: Optimization trade off parameters [4]

In the case of WCDMA networks the detailed planning by itself is an optimization process [4]. Hence, optimization is done by choosing the better location of node B sites and extracting it in to Google earth to see the nature of the location of node B. If the location of NB done in Atoll is at inappropriate location or coverage is not ensured well, the location will be changed to optimize the coverage while the nature of population density around the location is roughly considered.

5.2 Simulation Results

The simulation result ends up with **97** Node Bs to be deployed across the route for reliable and safe operation. The route can be served using only **48.5** Node Bs (48 two sector and 1 one sector Node Bs) for operation. In this thesis, safety and reliability are the key factors that must be upgraded. Hence, the additional **48.5** Node Bs are standby that will be operated in case of failure of the serving network, so that safety, availability and reliability are enhanced. Therefore, the deployed network is two independent networks that are divided by **even** and **odd** site names. i.e. (site 0_1, site 2, … , site 94 and site 94) and (site 1, site 3, …, site 95 and site 96_2). Site 0_1 and site 96_2 represents the one sector NBs that are found at the two most ends of the route. The list of Node Bs designed for suburban and rural are tabulated in (table 5-1).

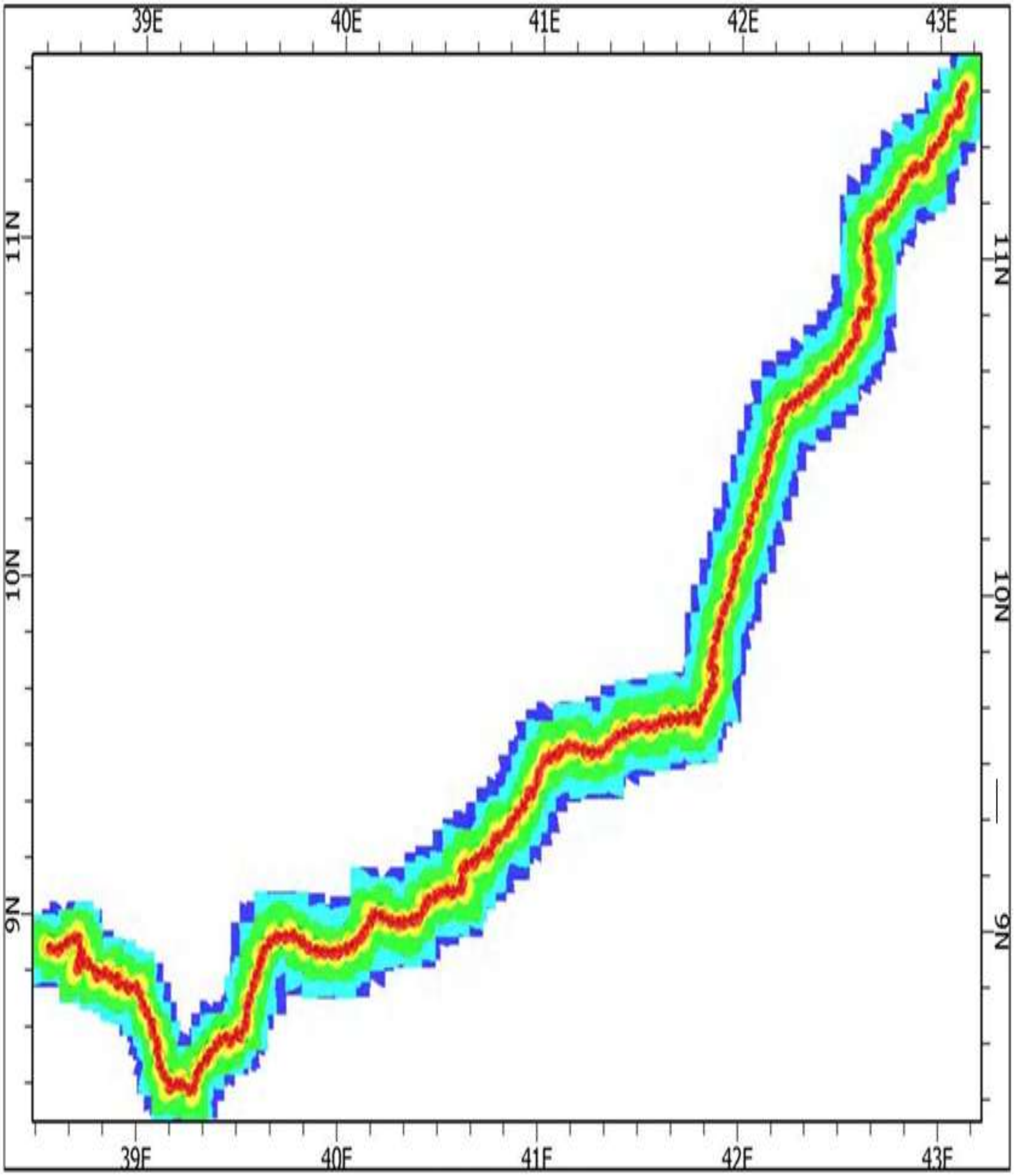


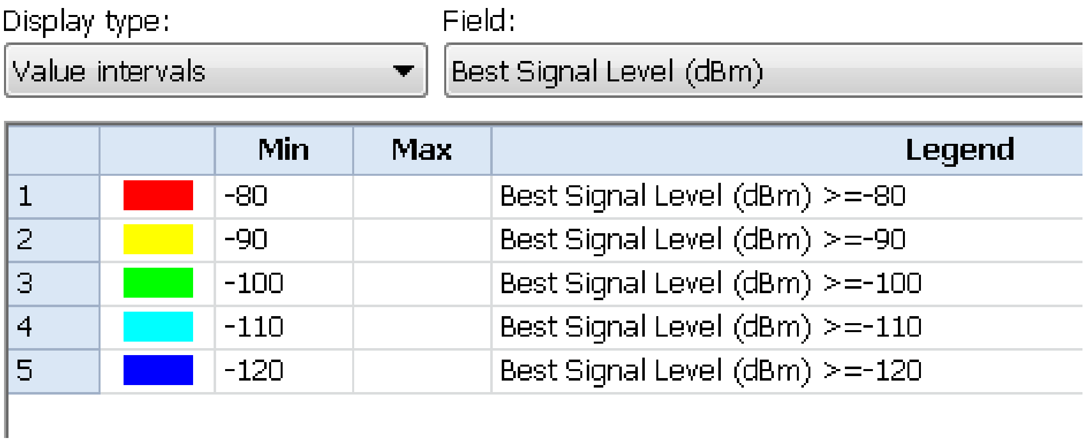
Figure 5-5: AA-Djibouti route UMTS-R coverage design with 97 nodes Bs

The image is taken without the node B transmitters to increase sight clarity of coverage.

Table 5-1: Nature and consideration of Node B sites on the route

S/N	**Geographical location (around)**	**Terrain type**	
		Suburban	**Rural**
1	Sebeta – Adama	Site 0 - site 25	-
2		-	Site 26 - site 56
3	Dire-dawa	Site 57 – site 67	-
4		-	Site 68 – site 88
5	Dewelle	Site 89 - site 96	-
6	**Total**	**45 sites**	**52 sites**

The different colors on the design called legend, shows the prediction property of the signal level. Figure 5-6 below shows the prediction properties used for each of the best signal level with different color.



Display type: Value intervals

Field: Best Signal Level (dBm)

		Min	Max	Legend
1	🟥	-80		Best Signal Level (dBm) >=-80
2	🟨	-90		Best Signal Level (dBm) >=-90
3	🟩	-100		Best Signal Level (dBm) >=-100
4	🟦	-110		Best Signal Level (dBm) >=-110
5	🟦	-120		Best Signal Level (dBm) >=-120

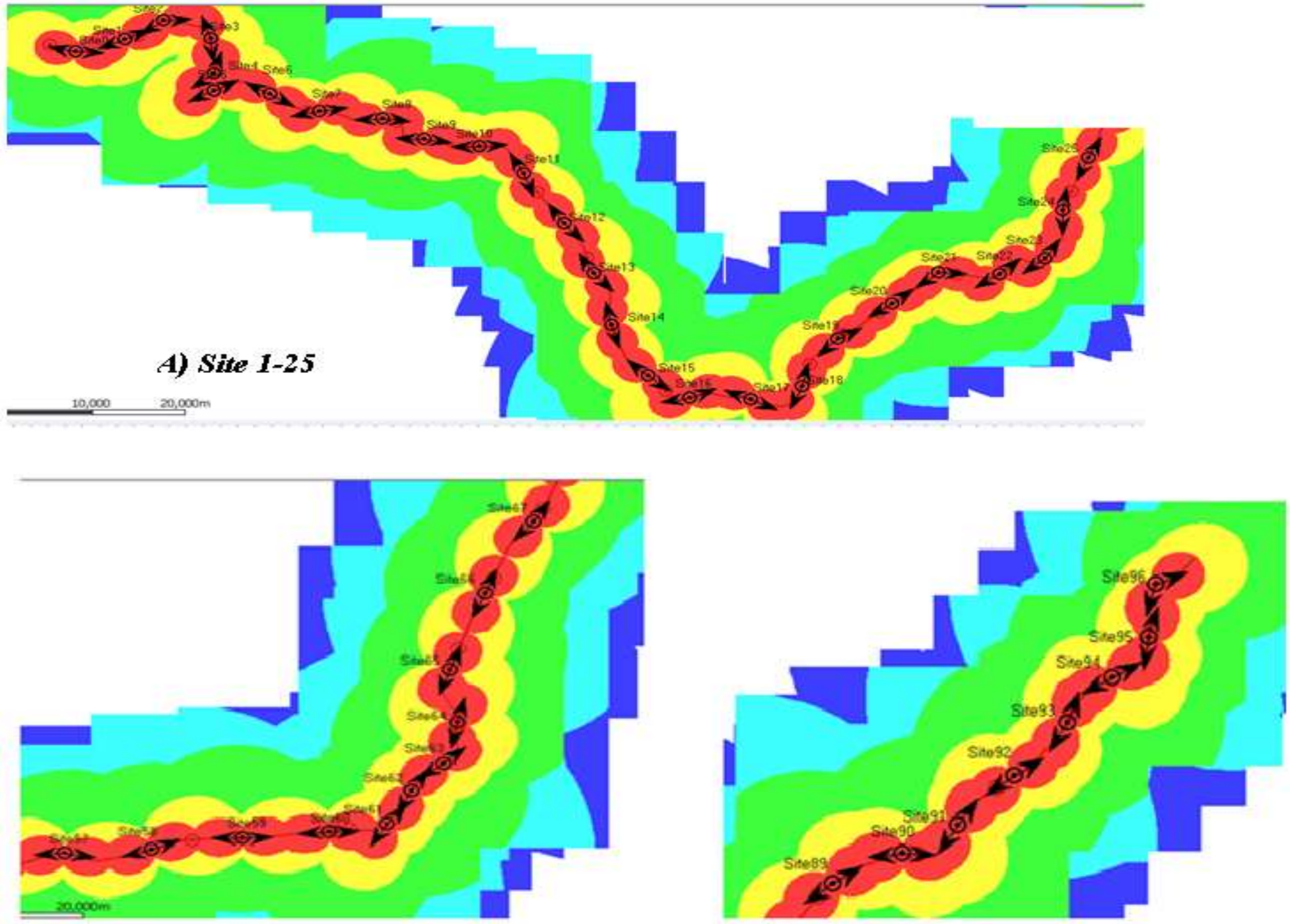
Figure 5-6: Used coverage prediction property

The exact site location in the coordinate (longitude, Latitude) of the entire 97 node Bs is tabulated in table (5-2) below. The right most side node B site names are deployed as a main system design and the left most site name column is the backup node B site names.

Table 5-2: Node B deployment point of the case study UMTS-R

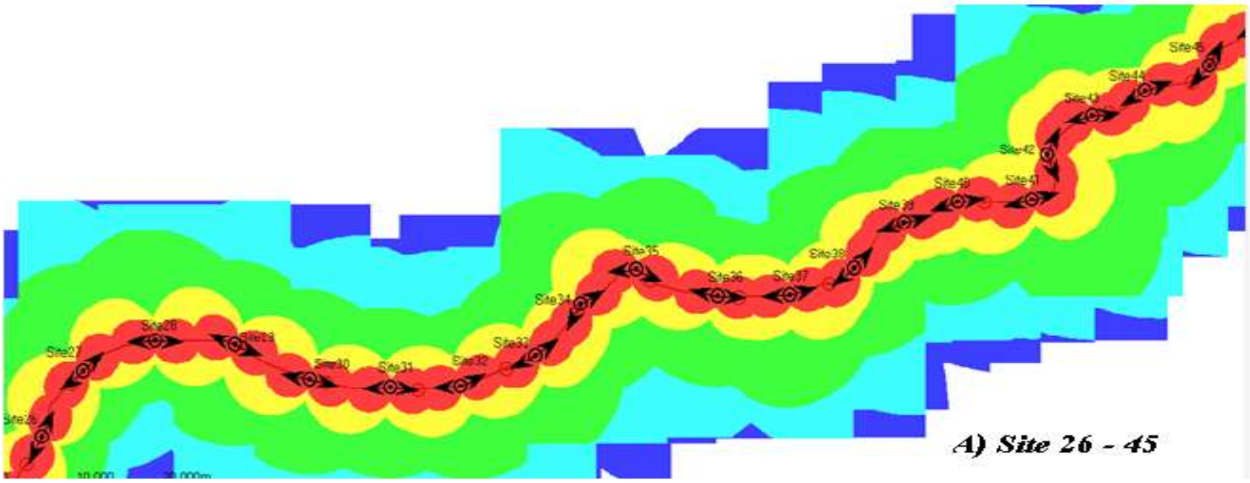
The main system NB sites			**Backup system NB sites**		
Site Name (Cell-Ethio)	**Longitude**	**Latitude**	**Site Name (Cell – Dji)**	**Longitude**	**Latitude**
Site 0	38°35'9.09"E	8°53'49.65"N	Site 1	38°37'59.76"E	8°54'41.24"N
Site 2	38°40'14.76"E	8°56'3.74"N	Site3	38°42'58.64"E	8°54'50.46"N
Site 4	38°43'12.19"E	8°52'23.35"N	Site5	38°43'14.11"E	8°51'10.76"N
Site 6	38°46'32.03"E	8°51'1.74"N	Site7	38°49'24.73"E	8°49'53.99"N
Site 8	38°53'5.03"E	8°49'25.43"N	Site9	38°55'32.54"E	8°48'0.74"N
Site 10	38°58'44.57"E	8°47'33.68"N	Site11	39°1'21.42"E	8°45'42.36"N
Site 12	39°3'47.38"E	8°42'16.24"N	Site13	39°5'31.24"E	8°38'48.71"N
Site 14	39°6'37.26"E	8°35'15.09"N	Site15	39°8'49.37"E	8°31'43.82"N
Site 16	39°11'16.1"E	8°30'13.43"N	Site17	39°14'49.03"E	8°30'9.77"N
Site 18	39°17'46.61"E	8°31'8.62"N	Site19	39°19'47.03"E	8°34'26.6"N
Site 20	39°22'55.04"E	8°36'56.86"N	Site21	39°25'36.45"E	8°39'11.64"N
Site 22	39°29'8.17"E	8°39'8.56"N	Site23	39°31'46.47"E	8°40'16"N
Site 24	39°32'47.02"E	8°43'37.26"N	Site25	39°34'10.7"E	8°47'18.78"N
Site 26	39°36'18.73"E	8°51'36.61"N	Site27	39°38'45.11"E	8°55'27.26"N
Site 28	39°43'0.99"E	8°57'16.66"N	Site29	39°47'48.35"E	8°57'5.63"N
Site 30	39°52'18.54"E	8°55'12.01"N	Site31	39°57'11"E	8°54'45.79"N
Site 32	40°1'22.93"E	8°54'53.32"N	Site33	40°5'48.05"E	8°56'44.71"N
Site 34	40°8'30.72"E	8°59'46.11"N	Site35	40°11'48.08"E	9°1'48.91"N
Site 36	40°16'42.45"E	9°0'17.09"N	Site37	40°21'1.31"E	9°0'25.36"N
Site 38	40°24'53"E	9°2'1.05"N	Site39	40°27'49.98"E	9°4'41.29"N
Site 40	40°31'4.03"E	9°5'55.15"N	Site41	40°35'28.72"E	9°6'6.63"N
Site 42	40°36'23.53"E	9°8'42.63"N	Site43	40°39'1.6"E	9°10'59.95"N

Site 44	40°42'12.83"E	9°12'27.49"N	Site45	40°46'2.16"E	9°13'56.82"N
Site 46	40°49'12.03"E	9°16'28.91"N	Site47	40°52'38.39"E	9°19'14.23"N
Site 48	40°56'12.1"E	9°22'28.54"N	Site49	40°58'55.21"E	9°24'54.8"N
Site 50	41°0'45.57"E	9°28'31.96"N	Site51	41°4'16.15"E	9°30'31.27"N
Site 52	41°7'26.33"E	9°32'1.42"N	Site53	41°12'15.31"E	9°31'56.35"N
Site 54	41°17'11.71"E	9°31'6.58"N	Site55	41°21'54.47"E	9°33'12.02"N
Site 56	41°26'28.43"E	9°35'5.62"N	Site57	41°30'58.79"E	9°36'10.97"N
Site 58	41°35'41.47"E	9°36'28.22"N	Site59	41°40'34.98"E	9°37'15.81"N
Site 60	41°45'14.85"E	9°37'42.57"N	Site61	41°48'23.38"E	9°38'12.71"N
Site 62	41°49'40.15"E	9°40'25.56"N	Site63	41°51'21.8"E	9°42'14.21"N
Site 64	41°52'7.83"E	9°44'53.96"N	Site65	41°51'41.44"E	9°48'20.7"N
Site 66	41°53'33.09"E	9°53'22.46"N	Site67	41°56'6.65"E	9°58'4.69"N
Site 68	41°58'14.48"E	10°2'53.57"N	Site69	41°59'56.46"E	10°6'50.58"N
Site 70	42°2'34.91"E	10°11'45.92"N	Site71	42°5'2.34"E	10°16'37.07"N
Site 72	42°7'10.65"E	10°20'55.65"N	Site73	42°9'6.36"E	10°25'27.92"N
Site 74	42°11'17.46"E	10°29'56.15"N	Site75	42°14'17.2"E	10°33'20.81"N
Site 76	42°18'48.96"E	10°35'12.64"N	Site77	42°23'9.44"E	10°37'31.15"N
Site 78	42°26'57.29"E	10°39'47.99"N	Site79	42°30'53.36"E	10°42'28.25"N
Site 80	42°33'57.18"E	10°45'19.77"N	Site81	42°35'7.91"E	10°48'51.03"N
Site 82	42°38'29.5"E	10°51'12.38"N	Site83	42°38'20.98"E	10°54'29.27"N
Site 84	42°38'25.48"E	10°58'14.47"N	Site85	42°37'46.3"E	11°2'55.11"N
Site 86	42°39'38.76"E	11°6'48.05"N	Site87	42°43'45.49"E	11°8'30.5"N
Site 88	42°47'9.13"E	11°11'32.43"N	Site89	42°49'57.93"E	11°14'41.01"N
Site 90	42°53'24.44"E	11°16'13.41"N	Site91	42°56'6.38"E	11°17'42.01"N
Site 92	42°58'51.41"E	11°20'13.28"N	Site93	43°1'29.42"E	11°22'56.2"N
Site 94	43°3'41.11"E	11°25'16.9"N	Site95	43°5'27.09"E	11°27'20.21"N
Site 96	43°5'47.64"E	11°30'2.89"N			



B) site 89-96 **C) Site 57-67**

Figure 5-7: Coverage simulations under the suburban considerations of the route



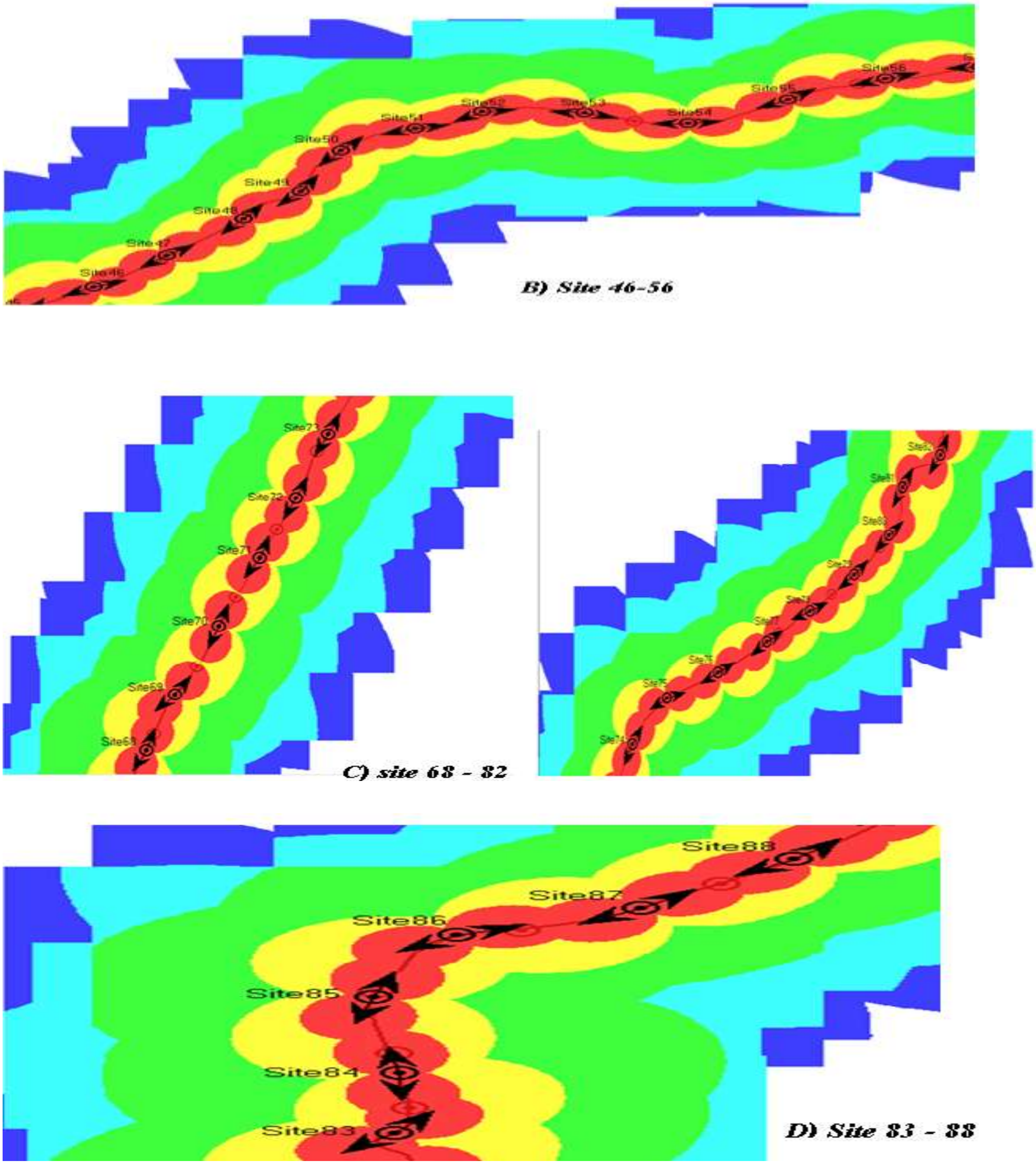


Figure 5-8: A), B), C) D), Coverage simulations under the rural considerations of the route

5.3 Capacity Estimation from Simulation Result

From table (5-1) and equation (4.47), the total data (DL capacity) of the route from the concept of capacity per area can be calculated. i.e. H = 45 and D = 52.

$$A_{av} = \frac{30.69 \times 45 + 189.7 \times 52}{97} = \frac{11245.4}{97} = \mathbf{115.9\,Km^2} \qquad (5.1a)$$

Hence, density of sites per Km^2 is:

$$\boldsymbol{S_{pk} = \frac{1}{A_{av}} = \frac{1}{115.9} = 0.00863\,\frac{sites}{Km^2}} \qquad (5.1b)$$

$$Capacity_{Max} = Num.of\ carrier\ per\ site \times maximum\ capacity\ per\ site \times S_{pk} \quad [5] \quad (5.1c)$$

$$Capacity_{max} = 1 \times 2Mbps \times 0.00863 = \mathbf{0.0173\,{}^{Mbps}/_{Km^2}} = \mathbf{34.93\,{}^{Kbps}/_{Km^2}}$$

Increasing the number of carriers per site increases the capacity. Hence, in case of high capacity requirement like large stations and depots it is recommended to increase the number of carrier per site.

The total area covered by the radio network is $= \frac{\mathbf{11245.4}}{\mathbf{2}} = \mathbf{5622.7\,Km^2}$ $\qquad (5.1d)$

This average area shows the area covered by a single two sector NB, providing **2Mbps** data**.** The UMTS-R system uses a total of **48.5** NBs for operation. Therefore, there is **2Mbps *48.5** = **97 Mbps** total data rate across the whole route.

In the case of DL capacity per user computed in section, a total of around 92020 mixed traffic subscribers per hour can be supported throughout the route.

Comparing with GSMR network capacity design for the case study computed in [3], which has a total data rate of **7.29622Mbps**, UMTS-R system provides us 8**9.70378Mbps** extra data in case of capacity per area and numerous subscribers per hour in case of mixed traffic capacity users. This result of estimated calculation indicates additional services including real time services across stations, in trains and control rooms can be added in the future if UMTS-R is deployed.

This mathematical analysis of area oriented is to show how much WCDMA data rate is greater than GSM. In the design optimizing the capacity and coverage is the key issue and difficulty of WCDMA for engineers. Hence, the data rate or capacity is dependent not only data rate per site but also mainly on the density of the site to optimize coverage and capacity. The distribution of UE over the area should be estimated at the time of deployment with the type of service and its corresponding data rate.

5.4 Result Analysis

In RF planning simulation, the propagation model takes the geographic data and other parameters into account and calculates propagation losses along the transmitter-receiver path. This allows predicting the received signal level at any given point.

In this thesis work, Google Earth view of the route is used to see effect of terrain. Any coverage prediction made on a Node B uses the propagation model to calculate its results. The coverage level of each **97** NBs is indicated by different colors according to the received signal level measured in **dBm** (figure 5-6). As the subscriber is near to the NB, a better signal strength is achieved.

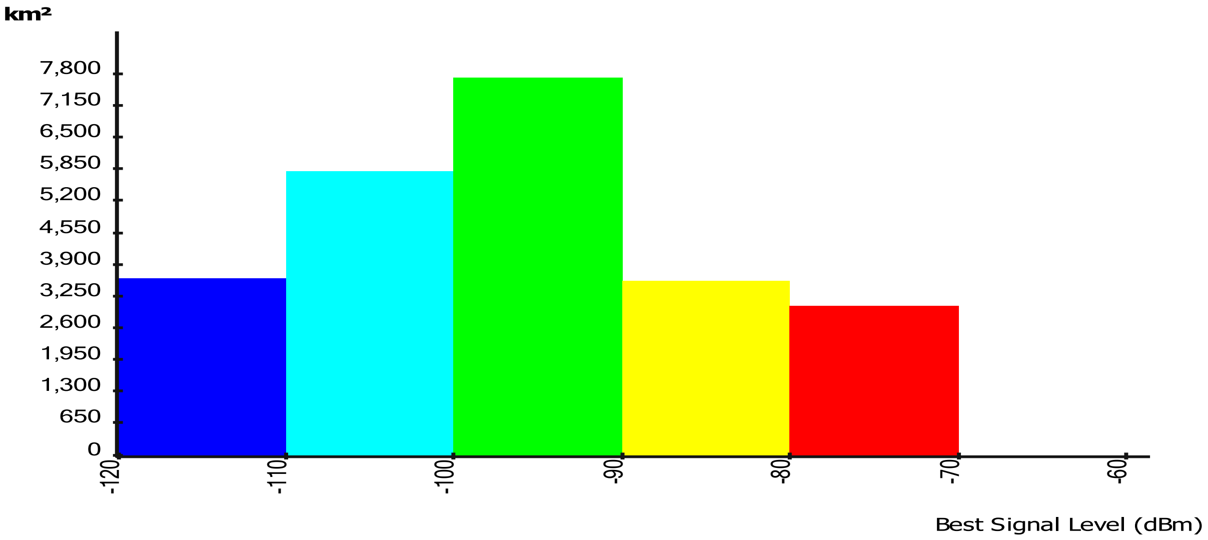


Figure 5-9: Total area coverage per each signal level

The area coverage across the route is taken from ATOLL simulation software as shown in figure 5-9. From the histogram, it is visible that the total area mentioned in equation (5.1c) is covered with and acceptable signal level.

Analysis taking random sites to ensure safe coverage by the 48.5 NBs is done. The coverage of the site remains with acceptable value as shown in figure 5-10. Some NB sites of backup design are removed and the coverage of the main system remains within the acceptable value. Hence, the **48.5** NBs, covers the route effectively.

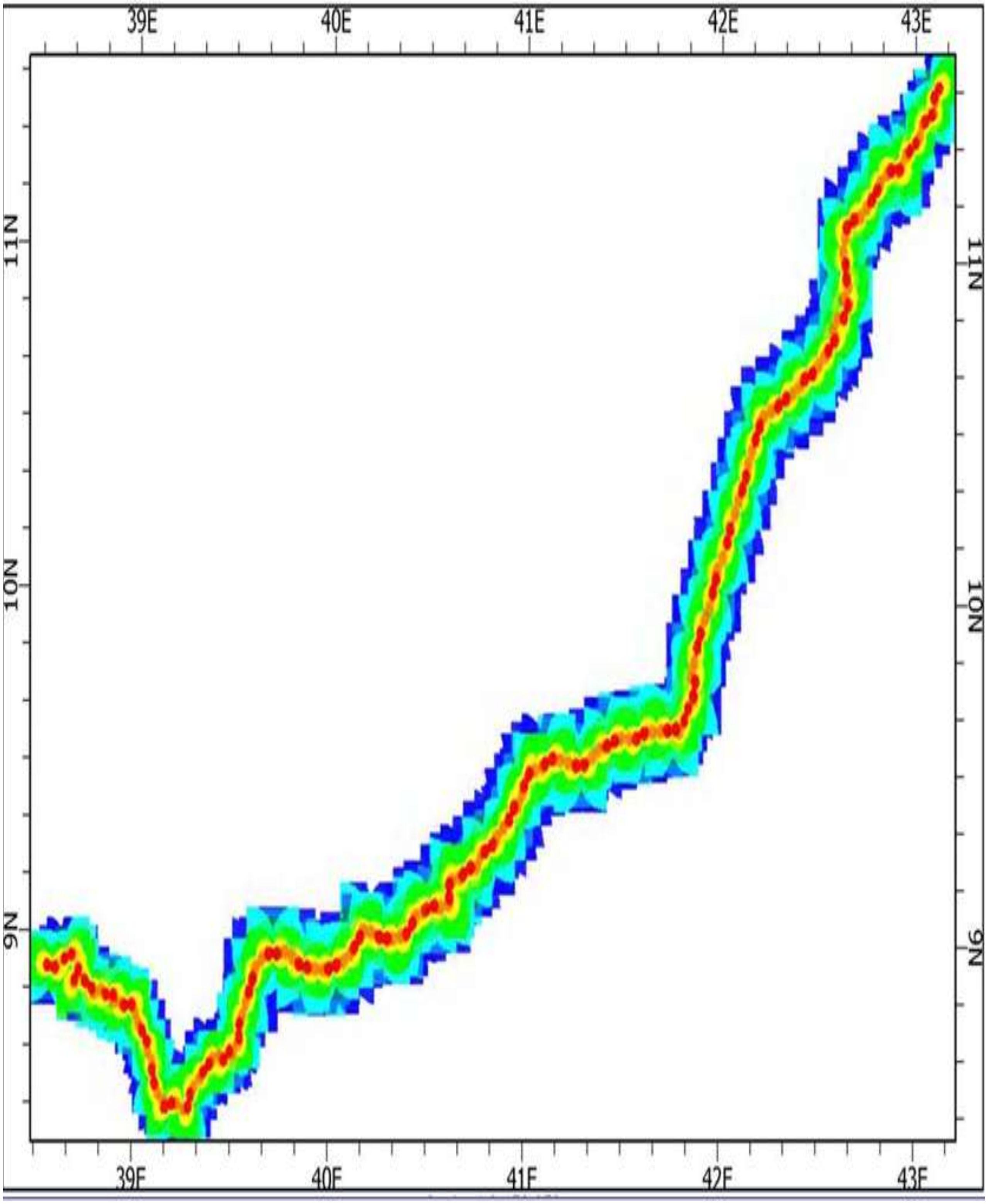


Figure 5-10: The signal level strength using only the 48.5 NBs

To make it visible, let us take random sites and see the coverage strength of the route by eliminating the backup NB deployment.

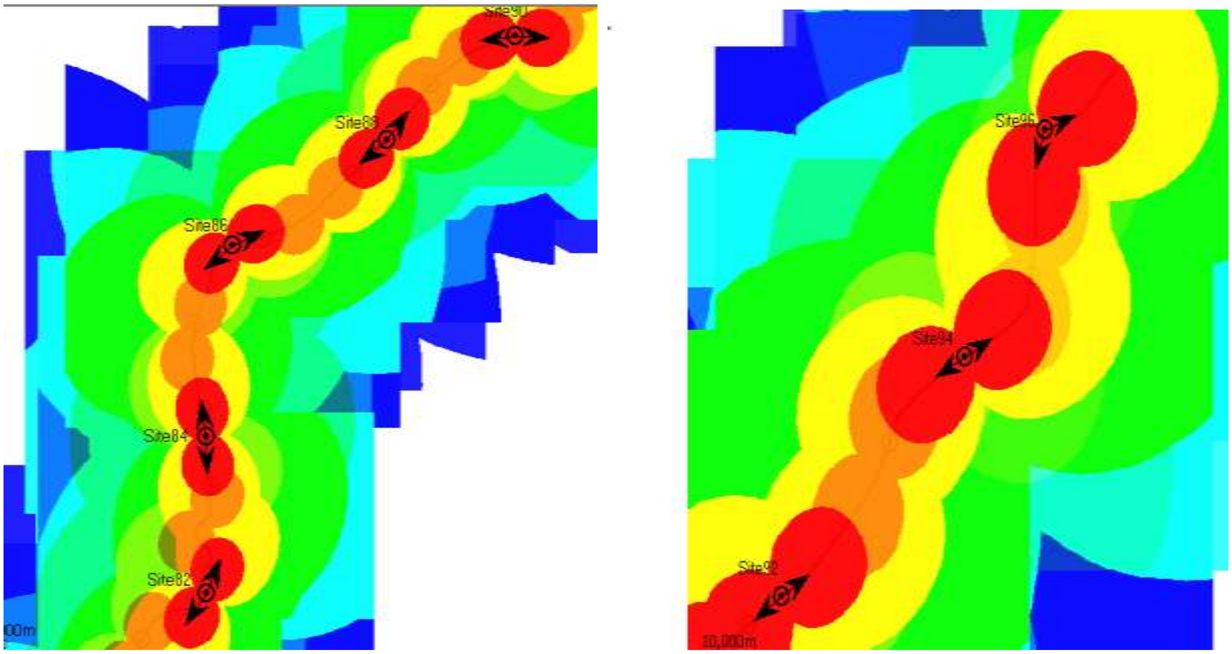
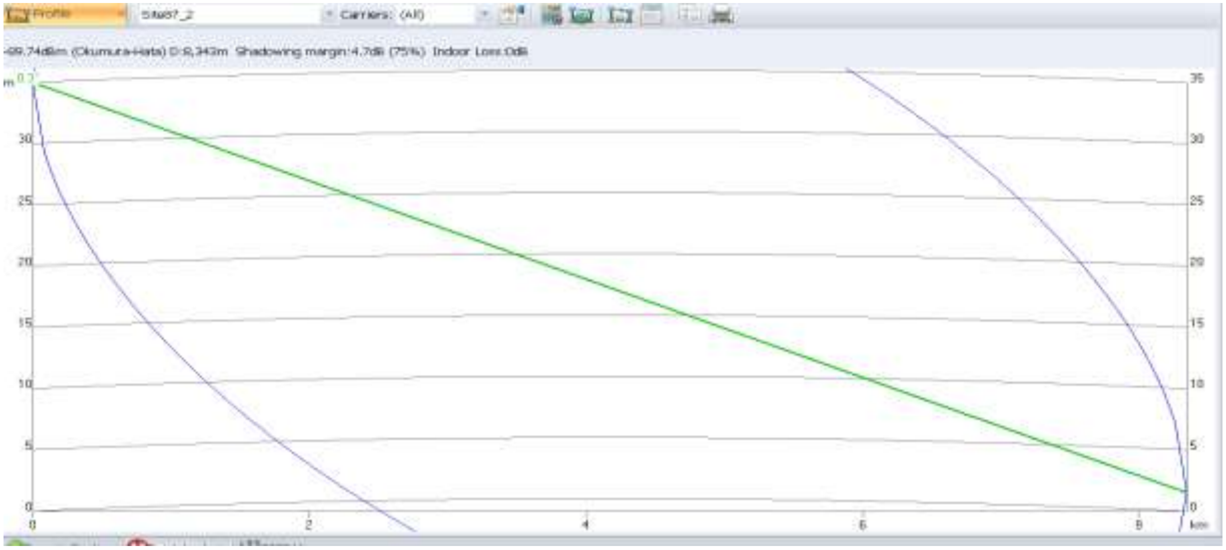


Figure 5-11: Sample result of coverage quality without redundancy



-89.74dBm (Okumura-Hata) D:8,343m Shadowing margin:4.7dB (75%) Indoor Loss:0dB

Figure 5-12: Geographic profile of randomly chosen site 87_2

In GSM-R, the minimum acceptable signal level is **-95dBm [**19, 22**]**. Hence, taking this standard assumption to the design of UMTS-R, the whole route without redundancy is confidently covered by the yellow signal level (best signal level 2 (-90 dBm), which is a strong signal. Hence, better coverage is ensured with the deployed number of NBs.

In the link budget the sensitivity is calculated to be **-120.17dBm** and is used as -120.2dBm, the standard value in ATOLL. Hence, the sensitivity level of a random site and its adjacent sites is within the acceptable range value as shown in figure 5-13.

Figure 5-13: Reception level including the adjacent sites

In the design, curves in the route are considered to have better radio network coverage to ensure safety by deploying the transmitter physically near to the curve.

The analyzed result shows every output is in the expected range and ensures the enhancement of safety, reliability, availability and capacity. More over a redundant service access sub system with total of 97 NBs is proven to give a qualitative signal level as per the GSM-R standard. The quantitative expression of system safety, reliability and availability is required. However, the quantity of those parameters is route specific which depends on the detail type of services and service location provided in the route, the quantity of service users and redundancy level of each subsystem. Hence, a quantitative measure of safety, reliability and availability will be done after the service type and real capacity plan of a route in need is specified in detail.

Chapter Six

6. Limitations, Conclusion and Recommendation

6.1 Limitations

This thesis would be done better and consume less time had the appropriate digital map and real data of the route had been provided. The process of creating a route on Google earth may not give the exact route (path). This error in accuracy of the route coordinates leads to miss positioning of sites during practical deployment. Moreover, the process of converting the path in to appropriate form that can be used by ATOLL software uses online and installed intermediate software which leads to complexity of the task to extract the input and consume more time. In addition to this the coverage planning tool used (ATOLL) is portable non-licensed software which is not efficient and sometimes fails. Hence, it leads to increase the number of simulation iterations to bring the final result. The capacity estimation is done theoretically due to the undefined additional services and their area of deployment which needs greater investigation.

6.2 Conclusion

The need of unlimited human interest forces to accelerate the rate of change of technology to fulfill the interest. The existing radio network of railway (GSM-R) will no more exist for the upcoming decades [5]. In this thesis a redundant UMTS-R access network subsystem for the case of AA-Djibouti railway route is designed as a candidate for the future capacity and coverage network system of railway system.

The design of UMTS-R using the WCDMA air interface is a challenging and complex task which highly demands optimizing coverage and capacity which are dependent on each another. Moreover, the reliability, safety and availability of the system are insured by designing redundant network system with each redundant sub system.

For the case study, Okumura-Hata path loss model is chosen reasonably and two environmental cases (Suburban and Rural) are considered for the system design. With the coordination of other online and inline software's, the Atoll (Atoll.us.v3.1.2.4478.Portable.MxBNET.REL.02) network simulation and optimization software is used to design the coverage with capacity per cell taking the nature of the environment into consideration. This design yields a total of 97 Node

Bs for both main system and backup system in which the system is fully operated with 48.5 Node Bs. Capacity estimation is made in two methods and a total of 97Mbps and 92020 mixed traffic subscribers per hour is obtained by data rate per **Km^2** and capacity by users method respectively. Compared with the GSM-R system designed for the case study which comes up with a total data rate of 7.9622Mbps, large extra data rate (capacity) is obtained. This extra data rate across the route will pave a way to deploy additional real and non real time services that will increase the safety and satisfaction of the system.

6.3 Recommendation

This work needs greater investigation in order to make complete and practical in all aspects for proving and enhancing its deployment. There are numerous ways to extend this work forward. This thesis provides an overview of implementing UMTS-R (especially the network access subsystem) for better operation. The radio network coverage needs further extensive assessment regarding to interference within the system and with extra radio network systems before practical deployment. Using this as a milestone, investigation of interference and its reduction mechanisms, redundant radio network controller (RNC) and UMTS terrestrial radio access network (UTRAN) design, analysis of electromagnetic compatibility (E MC) across the route, detail comparison of the design by taking other frequency of operation, design and comparison of the system with LTE, cost analysis of the system and re-evaluate the work by using advanced and power full simulating software and real digital map, developing mathematical analysis for optimization, investigate the possibility of UMTS-R and GSM-R cooperative operation to optimize cost and related are the tasks that can be further investigated before deployment.

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Appendix I

Part A

MATLAB simulation code of path loss Vs coverage distance comparison for Okumura- Hata and COST 231 propagation models: case of the suburban environment.

```
%Okumura-Hata Vs COST231 propagation model Comparison for coverage and
pathloss in suburban invironment
clc;
close all;
clear all;
%common parameters
d = 1:0.125:25; % distance in Km
fc = 850;
hm = 1.5; % UE antenna height in meter
hb = 35; % Node B height in meter
 % Okumura/Hata
ahm =3.2*(log10(11.75*hm)).^2 - 4.97; % considered as zero for fast moving
ahm=0;
% Okumura/Hata total path loss for sub urban
Loh = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hb))*log10(d) -
13.82*log10(hb)- ahm -9.794;% for suburban and assuming ahm=0
% COST 231
 ahr= 1.1*log10(fc)*hm - 1.56*log10(fc) - 0.8;
Lc2 = 46.3 +20.08*log10(hb)- ahr+ (44.9 -6.55*log10(hb))*log10(d);
figure(1);
plot(d, Loh, 'r *', d, Lc2, 'b +');
legend('Okumura-Hata f=850 MHz', 'COST231 f=850 MHz');
grid on;
xlabel('d [Km] at hb=35m');
ylabel('L [dB]');
title('Comparision of Okumura/Hata Model and COST231 model ');
```

Part B

MATLAB simulation code path loss Vs coverage distance comparison of Okumura- Hata propagation models for different environments

```
%Okumura Hatta model path loss and coverage analysis for d/t environments
clc;
close all;
clear all;
d = 1:0.125:25;
hm = 1.5;
hb1 = 35;
%hb2 = 100;
%hb3 = 200;
fc = 850;
% fc  >= 400MHz
 ahm = 3.2*(log10(11.75*hm)).^2 - 4.97; % ahm is assumed to be zero
 % A. Typical Urban
L50urban = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hb1))*log10(d) -
13.82*log10(hb1) - 0; %ahm = 0;
 % B. Typical Suburban
 L50suburban = L50urban - 9.794;

% C. Typical Rural
%4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94 = 16 dB taken for rural
L50rural = L50urban - 23.2;
figure(1);
plot(d, L50urban, 'r -');
hold on;
plot(d, L50suburban, 'b *');
hold on;
plot(d, L50rural, 'g +');
hold on;
legend('large urban hb=35',  'suburban hb=35',  'rural hb=35');
grid on;
xlabel(' coverage distance (d) [km]at f= 850MHz');
ylabel('path loss (L) [dB]');
title('Okumura-Hata Model for different environments');
```

Part C

MATLAB simulation code path loss Vs UE antenna height variation of Okumura- Hata and COST 231 propagation models

```
%Okumura/Hata v/s COST231 coparison of Path loss with variation of UE antenna height
clc;
close all;
clear all;
%common parameters
d =1.5; % distance in Km
%fc1 = 800;
fc = 850;
%fc3 = 900;
hm = 0.2:0.05:3; % UE antenna height in meter
hb = 35; % Node B height in meter
% Okumura/Hata
ahm =3.2*(log10(11.75*hm)).^2 - 4.97; % considered as zero for fast moving
ahm=0;
% Okumura/Hata total path loss for sub urban
Loh = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hb))*log10(d) - 13.82*log10(hb)- ahm -8;% for suburban and assuming ahm=0
% COST 231
    %COST 231 total Path loss
ahr= 1.1*log10(fc)*hm - 1.56*log10(fc) - 0.8;
Lc2 = 46.3 +20.08*log10(hb)- ahr+ (44.9 -6.55*log10(hb)).*log10(d);
figure(1);
plot(hm, Lc2, 'b*', hm, Loh, 'r +');
grid on;
legend ('COST 231', 'Okumura hata');
xlabel('UE height [m] at hb=35m');
ylabel('L [dB]');
title('Comparision of Okumura/Hata Model and COST231 model with variation of UE height');
```

Part D

MATLAB simulation code Throughput (Kbps) Vs noise raise (dB) result for voice only service (12.2Kbps) for varying interference levels

```
% #######MATLAB for code Noise rise vs Throughput ##########
clf;
clear figure;
N=1:100;
Blerv=0.1;% bit error value
Rv=12.2;% data rate of voice signal
p=5.1; %Eb/N0 for voice
w=3840; %chip rate
k=w/Rv;
v=0.67;
%variable values of interference factor
i1=0.65;
i2=0.95;
i3=1.1;
% the values of uplink noise raise
nul1=(p/k)*N*v*(i1+1);
nul2 =(p/k)*N*v*(i2+1);
nul3= (p/k)*N*v*(i3+1);
Th1=N*Rv*(1-Blerv);
%noise raises for the different interference factors
Nr1=-10*log(1-nul1); % noise raise in dB
Nr2 =-10*log(1-nul2);
Nr3= -10*log(1-nul3);
plot(Th1,Nr1,'r', Th1, Nr2, 'b +', Th1, Nr3, 'g-');
legend ('i= 0.65', 'i= 0.95', 'i=1.1');
hold on;
y=3; % case study noise raise
plot (Th1,y, '-');
title('Throughput Vs Noise rise ');
ylabel('Noise rise (dB)');
xlabel('Throughput (Kbps');
grid;
```