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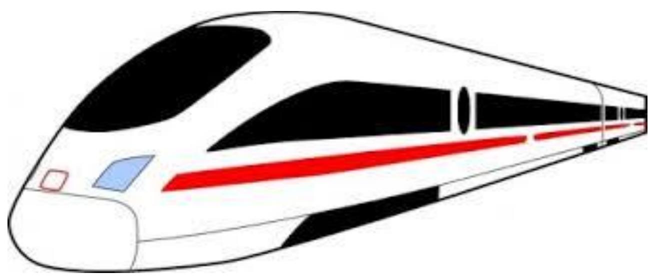

GSMR

Coverage and Capacity Planning

Awash-Woldia Rail Line

By: Abrha Teka Kahsay

May, 2015/2007

Addis Ababa, Ethiopia

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Advisor: Dr. Yalemzewd Negash

A Thesis Submitted in Partial Fulfillment of the Requirement for Degree of Master of Science in Electrical Engineering for Railway Systems

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Approved By Board of Examiners

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Declaration

I, the undersigned, declare that this thesis work is my original work, 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.

Name: Abrha Teka Kahsay

Signature: _______________

Place: Addis Ababa, Ethiopia

Date: May 29, 2015

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

Signature: __________________

Date: May 29, 2015

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Abstract

This thesis is intended to give a good understanding of GSMR radio network planning and perform a case study in Awash-Woldia rail line. It also considers future network implementation. In any cellular network, whether an expansion of the existing one or as a new technology to be deployed, the nominal planning of radio access network is considered as critical point. This is because it gives the first rough estimation to coverage and capacity.

In this thesis the coverage estimation is done by considering the nature of the route inspected from Google Earth. The number of base stations required to cover a given suburban rail line is determined. Appropriate propagation model is also selected. The capacity planning is done only in the analysis part; because of the unavailability and difficulty of having the traffic digital data for railway systems. The analytical results are simulated using radio planning tool called Atoll. Atoll is chosen over other dimensioning tools like Excel-based software and MATLAB for its in-depth input analysis, flexible working environment and being professional planning software.

After integration of the results in the dimensioning tool, the work is reviewed and iterations are performed till the desired results are reached. The simulations show that it is quite evident the planned network provides satisfactory results especially in coverage performance. Finally, we have found that **48** GSMR BTSs with total capacity of **3.35Mbps** for the entire Awash-Woldia rail line.

Keywords: GSMR, Dimensioning, Coverage, Capacity, Google Earth, Radio Network Planning

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List of Acronyms

2G	Second Generation
3G	Third Generations
3GPP	3rd Generation Partnership Project
AGCH	Access Grant Channel
ARFC	Absolute Radio Frequency Channel
ATC	Automatic Train Control
AUC	Authentication Center
BCCH	Broadcast Control Channel
BS	Base Station
BSC	Base Station Controller
BSS	Base Station System
BTS	Base Transceiver Station
CBH	Cell Broadcast Channel
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications Administrations
CUs	Cell Units
dBi	Decibels isotropic
DCS	Digital Cellular Service
DL	Download
EC	European Council
EDGE	Enhanced Data rates for GSM Evolution
E-GSM	Enhanced GSM
EIR	Equipment Identity Register
EIRENE	European Integrated Railway Radio Enhanced Network

eMLPP	enhanced Multi Level Precedence and Pre-emption Service
ERA	European Railway Agency
ERC	Ethiopia Railway Corporation
ERTMS	European Rail Traffic Management System
ETCS	Electronic Train Control System
ETSI	European Telecommunications Standards
FACCH	Fast Associated Control Channel
FCCH	Frequency Correction Channel
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FRS	Function Requirements Specifications
FS	Full Rate Speech
HS	Half Rate Speech
GCA	Group Call Areas
GCR	Group Call Reference
GID	Group ID
GMSK	Gaussian minimum shift keying
GPRS	General Packet Radio Services
GPS	Global Positioning System
GSM	Global Systems for Mobile Communications
GSMR	Global Systems for Mobiles Communications-Railway
HCSs	Hierarchical Cell Structures
HLR	Home Location Register
ID	Identification
IMEI	International Mobile Equipment Identity

IMP	Inter Modulation Product
IMSI	International Mobile Subscriber Identity
ITU-T	International Telecommunication Union -Telecommunication Standardization Sector
LOS	Line of Sight
LTE	Long Term Evolution
MAPL	Maximum Allowable Pass Loss
ME	Mobile Equipment
MORANE	Mobile Radio for Railways Networks in Europe
Mph	miles per hour
MSC	Mobile Switching Center
NCH	Notification Channel
NLOS	Non-Line of Sight
NSS	Network Switching System
PBH	Peak Busy Hour
PCH	Paging Channel
P-GSM	Public GSM
PL	Pass Loss
PPT	PUSH TO TALK
QoS	Quality of Service
RACH	Random Access channel
RF	Radio Frequency
SACCH	Slow Associated Control Channel
SCH	Synchronization Channel
SDCCH	Standalone Dedicated Control Channel
SIM	Subscriber Identification Module

SINR	Signal to Intereference+Noise Ratio
SMG	Special Mobile Group
SRS	System Requirements Specifications
TCH	Traffic Channel
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TN	Time Slot number
TRX	Transceiver
UIC	International Union of Railways
UL	Upload
VBS	Voice Broadcast Service
VGSC	Voice Group Call Service
VLR	Visitor Location Register
WiMAX	Worldwide Interoperability for Microwave Access

Chapter One

1. Introduction

1.1 Background Information

GSMR, Global System for Mobile Communications-Railway or GSM Railway is an international wireless communications standard for railway communication and applications. It is a sub-system of European Rail Traffic Management System (ERTMS), used for communication between train and railway regulation control centers. The system is based on GSM and EIRENE-MORANE specifications which guarantee performance at speeds up to 500 km/h without any communication loss. It is the best and efficient technology to implement Automatic Train Control, ATP. It focuses on safety, reliability, prevention of accidents, emergency communication and serving people traveling on railways.

GSMR benefits from the economies of scale of its GSM technology heritage, aiming at being a cost efficient digital replacement for existing incompatible in-track cable and analogue railway radio networks. Over 35 different such systems are reported to exist in Europe alone [1].

GSMR is standardized worldwide. The standard is the result of over ten years of collaboration between the various European railway companies, with the goal of achieving interoperability using a single communication platform. GSMR is part of the ERTMS standard and carries the signaling information directly to the train driver, enabling higher train speeds and traffic density with a high level of safety. GSMR is also responsible for key commands in rail dispatch and control, and a fault in the GSMR system could lead to commuter chaos or a serious accident. Therefore, extremely stringent reliability requirements are imposed on every GSMR network.

GSMR is a standardized to be implemented in either the E-GSM, 900 MHz-GSM or Digital Cellular Service, DCS 1800, 1800 MHz-GSM, frequency band which are both being used around the world. The range of the band is different in different countries; GSMR has the ability to smoothly integrate new services defined in future.

The frequency spectrum allocated for GSMR is limited to 4 MHz, which means 19 frequency channels in most countries. Optimized frequency reuse pattern to increase network capacity, microcells in areas with high density like railway stations and overlay solutions with speed sensitive handover are under introduction in public GSM and thus may only be slightly modified for railway specific use. Differences exist in the network layout and planning deriving from the critical needs of railway networks [2].

GSMR uses Gaussian Minimum Shift Keying (GMSK) modulation technique and is a Time Division Multiple Access (TDMA) system. Data transmission is made of periodical TDMA frames with a period of 4.615 ms, for each carrier frequency or physical channel. Each TDMA frame is divided in 8 time slots, named logical channels with each time-slot 577 μs long, carrying 148 bits of information [3].

1.2 Statement of the Problem

Time returns us about a century to those days railway transportation begun in Ethiopia, the single line, Awash-Woldia rail track line. Despite of the long time of operation the system stayed not developed as it used to function in traditional and not updated systems in the past times. So many reasons can be suggested for but it is out of the scope of this project. Among those systems the train protection system is the one and vital as it is directly related with safety of passengers and freight aboard on the trains. That is the safety issue why every railway systems worldwide have been walking for better innovations to protect their trains and customers as much as they could.

During all the past times Ethiopian Railway System has been using an analogue train protection system. But using those analogue systems had no a severe effect on safety protection because the operational speed of the trains was not out of its control. Not only this, because the railway network was only a single line and the number of trains to be managed was very few; it was not in a need of a complex train protection system. It is observed that manual and early founded systems were operating in acceptable efficiency for that reason. For sure, the demand for automated and modern ways of train protection systems is the outcome of this new Ethiopian railway era with high speed operation and increased traffic; so that complex network structure…!

Even though the contract taken for signaling of the line by Bombardier is not GSMR, considering its worldwide acceptance, standardization and efficiency, it is not a long time that GSMR will be the backbone for automatic train protection system in all the Ethiopian high speed inter-regional railway lines like in other countries.

But it will not be a copy paste game when someone thinks to implement the technology for Ethiopian railway corridors. It needs a 'translation' for its all like capacity, coverage, configuration and etc. The desire to learn how to plan affordable GSMR service in Awash-Woldia rail line is the motivating factor in pursuing this thesis work.

1.3 Thesis Objectives

1.3.1 General Objective

The general objective of this thesis work is to come up with detailed coverage and capacity planning of GSMR for future deployment in Awash-Woldia rail line. And in addition:

- Place a milestone for the Ethiopian Railways Systems Automatic Train Protection being the first GSMR planning work and being an initial input for future works.
- Identifying factors that affect GSMR coverage and capacity planning.

1.3.2 Specific Objective

Specifically this work is aimed to:

- To select an appropriate propagation model for GSMR deployment in Awash-Woldia line
- To determine the number of CUs required covering the line of interest.
- To estimate the data density requirement for supporting a specified offered train traffic with a standard quality of service
- To evaluate the performance of the planned network using computer simulation.

1.4 Review of Literatures

There have been several works done on the area of GSMR coverage and capacity planning. Some of recently published articles related to this work are reviewed as follows:

Corneliu Mihail ALEXANDRESCU, Lăcrămioara-Mihaela NEMŢOI (2011): This paper describes in detail a radio planning procedure for the design of a railway radio communications network based on the ETSI GSM standard (GSMR), compliant with all the mandatory requirements specified by the International Union of Railways (UIC). The approach of the proposed radio planning procedure is highly practical and original in itself. It starts with clear indications on why and how to manipulate the digital cartography dataset to accurately represent the railway infrastructure, and eventually providing all the cell and frequency planning deliverables required to dimension a GSMR network that covers the Bucuresti-Constanţa railway corridor, 225 km. The coverage of the GSMR system is also calculated on the base of Base Station parameters and appropriate propagation models. Simulation is done using ICS Telecom planning software [4].

Valentin I. Popov, Andrei J. Baranovskii (2010): According to this paper, terrain types and geographical features should be taken into account during GSMR radio planning. The cell and frequency planning process results in the generation of the initial data for the design of each GSMR base station. The link budget is a calculation encompassing all of the technical factors associated with the uplink, transceiver, and downlink to determine, amongst other things, the maximum permissible air interface path loss. The link budget can be separated into two calculations, one for the downlink and one for the uplink. In order to calculate the link budget for the downlink, the first step is to calculate the base transceiver station effective isotropic radiated power, EIRP. This is the effective power that is radiated from the base station antenna [5].

Jørgen Binningsbø (2006): This paper tells the GSMR capacity planning is got after good estimation of the traffic needed. This includes for instance; voice and data communication for train conveying, administrative personnel, operation and maintenance personnel, data communication for information to passengers, train signals, etc. The link budget calculation uses various parameters such as; base station parameters, antenna height gain, receiver sensitivity, fading margins and losses like feeder loss. This model used is based on measurements done on Netcom sites in Hallingdal which is tuned to clutters forest and agricultural land [6].

1.5 Methodology

The thesis work is conducted as a case study based on the published technical papers from academic institutions, GSMR planning companies such as Huawei and Siemens. The flow chart below shows the methodology followed during this thesis work.

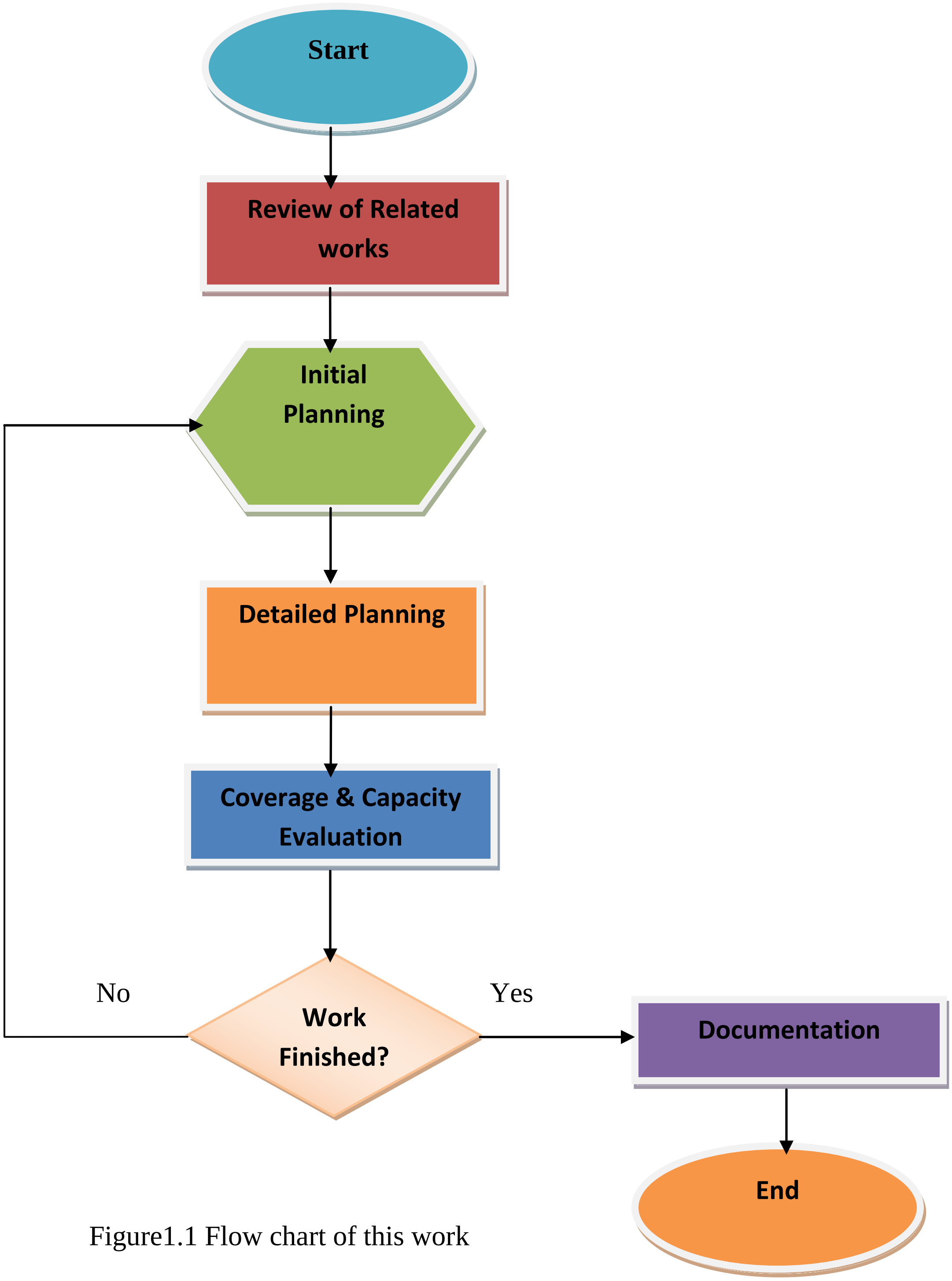


Figure1.1 Flow chart of this work

Chapter Two

2. GSMR Review

GSMR is an international wireless standard for railway communication and applications, a subsystem of ERTMS, used for communication between train and railway regulation control centers. The system is based on GSM and EIRENE - MORANE specifications which guarantee performance at the speed up to 500 km/h (310 mph), without any communication loss.

Built on GSM technology, GSMR is a secure platform for voice and data communication for railway security, service and communications. It is used as a layer on which security and train tracking applications run, as well as video surveillance, passenger information system and cargo tracking. GSMR is the standard for wireless railway communications in Europe, Asia and North Africa, replacing dozens of legacy standards in use prior to the developments on itself [7].

For the network planning, the coverage level is defined in terms of area and time where the minimum signal criteria are achieved. This works in full compliance with the European Integrated Railway Radio Enhanced Network (EIRENE) specifications and with the customers' requirements. The level of coverage should be at least 95% of the time over 95% of the designated coverage area for a radio installed in a vehicle with an external antenna.

GSMR, the wireless component of ETCS Level 2, is a multi-function radio solution supporting critical train control data, train to wayside voice communication, and multiple voice channels for all railroad personnel and passenger information. This includes various special railroad requested services such as emergency, group or broadcast calls, functional or location dependent addressing, call prioritizing, paging, telemetry, and other data in a single, integrated radio solution. ETCS Level 2 with GSMR is a broadly service-proven, certified, multiply-sourced integrated ATC and radio solution. It complies with project and technical characteristics suited to implement with low risk and cost, if suitable radio frequencies can be acquired.

GSMR in most of the world is allocated 2 x 4 MHz blocks, in some countries this has been enhanced with additional 2 x 3 MHz neighboring blocks.

The current version of GSMR relies on circuit switching to carry ETCS data, which in essence requires one time slot to be dedicated for each train in each cell contained within the given movement authority. The UIC is investigating more spectrally efficient modulation schemes and packet switched radio networks. With packet-switched schemes, multiple mobile data users can share a time slot and the overall capacity of a fixed number of channels is increased compared to a circuit switched scheme.

Enhanced Data rates for GSM Evolution (EDGE) and LTE are considered "future" technologies by the UIC, and current focus is on investigating the suitability of General Packet Radio Service (GPRS) for ERTMS. Just as GSMR leveraged GSM commercial cellular technology for railroad usage, the UIC's investigation follows that trend with the investigation of GPRS. GPRS is a packet oriented mobile data service on the 2G and 3G GSM systems. GPRS standards are maintained by the 3rd Generation Partnership Project (3GPP) and are a widely deployed wireless data service, available now with most GSM networks. GPRS, which extends GSM to support packet switching of data, is a more spectrally efficient technology compared to GSM circuit switched data and therefore, less spectrum is required to support the same number of users. The spectrum issues applicable to GSMR also apply to GSMR with GPRS [7].

2.1 Why GSMR

European Railways chose the wireless network of GSMR as the maintenance of cables or overhead lines had become costlier. Moreover, emergency communication becomes easier and far more prompt against cable communication which has sockets placed at fixed intervals. For instance, for Indian Railways additional benefit arises with the elimination of the frequent need to replace stolen cable especially in the eastern regions, also avoid infrastructure for radio patching covering breaks in cable. The savings in lifecycle costs by replacing cable are so enormous that there was no need to perform a cost benefit analysis [14].

GSMR enables voice/ data communication between train controller, drivers/guards of trains, and station masters within the controlled area. Also communications among running staff of different trains, trackside staff, shunting staff etc. are envisaged. GSMR is standardized by railways and industry in EIRENE, validated in MORANE and in commercial operation since more than 10 years. It provides operational and commercial advantages to railways and makes them more competitive in a changing environment as it is featured by:

Interoperability

Railway communication without system borders**:**

- Increase average travel speeds through optimized breaking points
- Increase maximum speeds with line of sight signals replaced with radio
- Increase track capacity through minimized inter-train distance
- Guaranteed high speed (500 km/h) and conventional lines operation seamless border crossing

Efficiency

Railway communication at reduced cost:

- Reduce infrastructure cost by using widely adopted GSM technology
- Only one Radio system for all applications including ETCS
- Reduce infrastructure cost through competition

2.2 Basic GSMR Services

In 1993, Union Internationale des Chemins de Fer (UIC) designated GSM as the platform for future railway communication services. To meet the communication requirements on railways, ETSI SMG introduced ASCI; including eMLPP (enhanced Multi Level Precedence and Pre-emption Service), VBS (Voice Broadcast Service), and VGSC (Voice Group Call Service), to GSM phase 2+ standards [12].

2.2.1 eMLPP

eMLPP includes precedence and pre-emption. The precedence means that you can allocate certain priority authority to a GSM subscriber, and the subscriber can select a priority level for each call within its authority. The way for the subscriber to set up a call varies with priority level. The calls with higher priority levels are set up faster than the calls with lower priority levels.

The pre-emption means that the calls with higher priority levels can pre-empt the resources of the calls with lower priority levels when network resources (including processing capability, signaling channel, and traffic channel) are scarce. To ensure the conversation of the calls with higher priority levels, the network can disconnect the conversation of the calls with lower priorities.

eMLPP was put forwarded in 1994. At that time, ETSI (European Telecommunications Standards Institute) was establishing the rules for GSM phase 2, so eMLPP was researched in GSM phase 2+ instead of GSM phase 2. In May 1997, ETSI issued GSM 02.67 (ETS 300 924) eMLPP phase 1 and GSM 03.67 (ETS 300 932) eMLPP phase 2. Currently, the standardization of eMLPP is being implemented. In ISDN services is there a MLPP (see ITU-T I.255.3), and eMLPP is developed from the MLPP and GSM network characteristics.

2.2.2 VGCS

Voice Group Call Service corresponds to 03.68 protocols. According to VGCS, a network is divided in to Multiple Group Call Areas (GCA). And Multiple Group ID (GID) is defined in each GCA. A Group Call Reference (GCR = GCA + GID) is an exclusive one in the network. The roles involved in VGCS are speakers, receivers, and dispatchers.

When an MS starts a group call, the network side will set up one group call channel in each cell within the GCA, and will send group call messages on the Notification Channel (NCH), which is similar to the paging channel. When the MSs belonging to this group detect notification messages on the NCH, they automatically adjust them to the paging channel to receive the messages. When intending to start the conversation, any receiver can press the key PPT (PUSH TO TALK). The dispatcher own dedicated channels, so it can start the conversation any time. For other subscribers in the group call, only one of which can be the speaker, the others are receivers.

2.2.3 VBS

VBS can be realized on the VGCS platform. For VBS, only the subscriber starting the call can be the speaker during the conversation, and other subscribers are all receivers. Because no uplink access control is required for VBS, it is realized easier than VGCS.

2.3 GSMR Specific Features

Due to higher security requirements in railway traffic operation, additional security features for GSMR have been introduced. Some examples are:

- **Group- and Broadcast-Functions** which allow simultaneous call setup to several mobile radio units, while voice information can be forwarded to many subscribers at the same time. It delivers features such as VGCS, VBS.
- GSMR can distinguish between **call types with high or low priority,** for example, emergency calls always have the highest priority and interrupt other calls if needed.
- **Functional Addressing** connects subscribers with persons who have a specific function, such as the train driver currently on duty. The calling party just needs to know the train number and the intelligent network is able to automatically connect to the currently registered train driver.
- By means of **Location Independent Addressing**, callers are connected with the personnel on duty at a certain location. For example on line **A-C**, the train driver is able to press the dispatcher button in **D** station automatically providing a connection to the dispatcher responsible for the right track. By pressing the same button on the way to **C**, for example in **B**, the driver will be connected with the dispatcher responsible for the **B** area.

2.4 GSMR Specific Requirements

GSMR networks have to fulfill tight availability and performance requirements of the railway radio services. The special conditions and requirements of a railway communication system such as the linear train movement along the tracks are laid down in the EIRENE SRS V15 specification. Both the line oriented GSMR network and ERTMS requires a very high quality of service. Especially the application ETCS needs a permanent connection with a traffic load of 1 ERLANG per train and a permanent radio link availability of 100 % in time. These requirements of GSMR and ETCS for continuous radio link availability are in accordance with the UIC/EC/EIRENE definitions. The minimum performance requirements for railway radio services based on GSMR are defined in UIC EIRENE FRS V7 and SRS V15 (May 2006). The documents are listed in Annex A of the Technical Specification for Interoperability Control Command and Signaling, based on EC Directives 96/48 and 2001/16. The minimum coverage probability is defined as a probability value of at least 95% for any location interval of a length of 100m for which the measured signal level at the cab radio (train-mounted MS) antenna shall be higher or equal to the reference value of -95 dBm depending on the service and speed of trains whereas for public mobile GSM networks uncorrelated locations are evaluated and the 95% criterion is averaged over all possible locations. According to the EIRENE specification for GSMR systems the data transmissions for train control require an instantaneously available access in real-time.

In spite of the above mentioned service differences between GSMR and public mobile networks, the GSMR air-interface is fully radio-compatible with the standard for GSM networks.

Noting that Directive 2008/57/EC of 17 June 2008 on the interoperability of the rail system within the Community shall be complied with, continuity of service of GSMR shall also be ensured at borders. This means in particular that national measures intended to prevent or to mitigate interference between public mobile networks and GSMR networks may not impede the cross-border operation of cab radios mounted in railway vehicles [15].

2.5 GSMR Radio Access Technology

GSMR is based on the cellular GSM technology, with further enhancements specific to the requirements of railroad operation, such as train control. In general, GSMR uses characteristics that are identical or similar to those of the GSM system, such as frequency spacing (200 kHz), modulation (Gaussian minimum shift keying, GMSK) and access type (TDMA, TDD/FDD), the frequencies of GSMR being extended below the frequencies of the GSM-900 standard.

Channel spacing is 200 kHz and the modulation used is Gaussian Minimum Shift Keying, GMSK modulation. GSMR is a TDMA (Time Division Multiple Access) system. Data transmission is made of periodical TDMA frames with a period of 4.615 ms, for each carrier frequency or physical channel. Each TDMA frame is divided in 8 time-slots named logical channels, each 577 μs long, carrying 148 bits of information [8].

TDMA is a digital technique that divides a single channel or band into time slots. Each time slot is used to transmit one byte or another digital segment of each signal in sequential serial data format. This technique works well with slow voice data signals, but it is also useful for compressed video and other high-speed data.

The GPRS for data communications up to 14.4 Kbit/s is supported by GSMR for data transport in the same way as with the regular GSM system. It serves customized applications such as automatic train control (ATC) and electronic train control system (ETCS) for remote or automatic control of train movements and monitoring as well as functional addressing (calling a user by an assigned function rather than by a fixed number) and location-dependent addressing.

TDMA is the only technology that offers an efficient utilization of hierarchical cell structures (HCSs) offering Pico, Micro, and Macro cells. Because of its inherent compatibility with FDMA analog systems, TDMA allows service compatibility with the use of dual-mode handsets.

2.6 GSM Radio Interface

2.6.1 General Characteristics

The system is based on frequency-division duplex (FDD), which means that the uplink (radio link from the mobile to the network-that is, mobile transmit, base receive), and downlink (from the network to the mobile-that is, base transmit, mobile receive) are transmitted on different frequency bands. For instance, in the 900-MHz E-GSM band, the block 880-915 MHz is used for transmission from mobiles to network, and the block 925-960 MHz is used for the transmission from network to mobiles. Table 2.1 gives a summary of uplink and downlink frequency bands for the different GSM systems. Being one type of GSM, GSMR has also different frequencies in different countries [9].

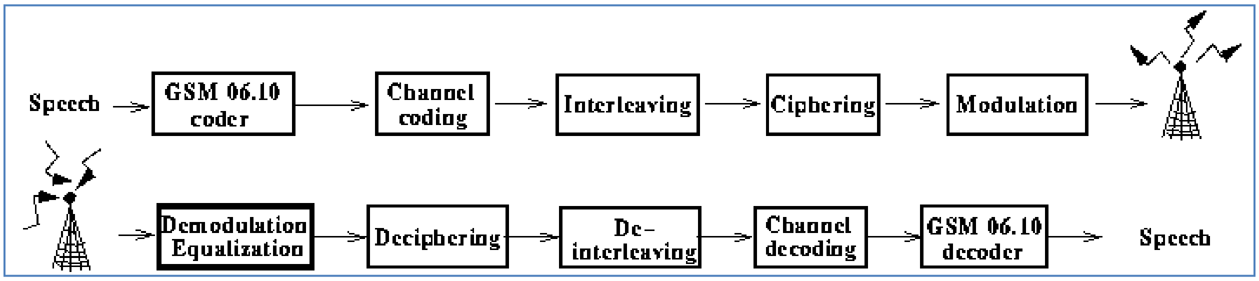


Figure2.1: TDMA transmitter and receiver, Speech [9]

There are different ways of sharing the physical resource among all the users in a radio system, and this is called the multiple-access method. The multiple-access scheme defines how simultaneous communications share the GSM radio spectrum. The various multiple-access techniques in use in radio systems are frequency-division multiple access (FDMA), TDMA, and code-division multiple access (CDMA). GSM is based on both FDMA and TDMA techniques.

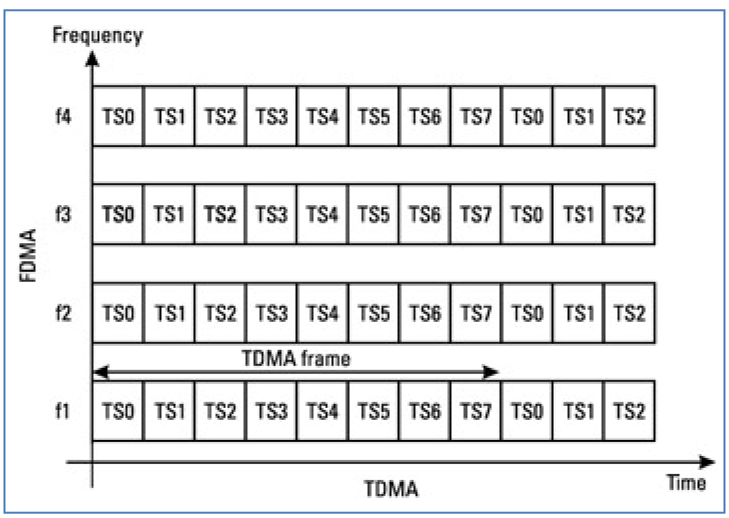


Figure2.2: TDMA and FDMA [8].

FDMA consists in dividing the frequency band of the system into several channels. In GSM, each RF channel has a bandwidth of 200 kHz, which is used to convey radio modulated signals, or carriers. Each pair of uplink/ downlink channels is called an Absolute Radio Frequency Channel, ARFC and is assigned an ARFC number, ARFCN.

TDMA is the division of the time into intervals: within a frequency channel, the time is divided into time slots. This division allows eight users to be multiplexed on the same carrier frequency, each user being assigned a single time slot. A packet of data information, called a burst, is transmitted during a time slot. The succession of eight time slots is called a TDMA frame, and each time slot belonging to a TDMA frame is identified by a time slot number (TN), from 0 to 7.

2.6.2 Logical Channels

The association of a radio frequency channel and a time slot-the pair ARFCN and TN-uniquely defines a physical channel on both the uplink and the downlink: On top of the physical channels, logical channels are mapped to convey the information of voice, data, and signaling. This signaling information is used for setting up a call, or to adapt the link to rapidly changing radio conditions, or to manage handovers, to give a few examples. Logical channels can be seen as pipes, each one used for a different purpose by the higher layers of the system.

Two types of logical channels exist, traffic channels and control channels. Among the control channels, according to their functions, four classes are defined: broadcast, dedicated, common, and associated. A broadcast channel is used by the network (in downlink only) to send general information to the MSs. A channel is said to be dedicated if only one MS can transmit or receive in the ARFCN-TN defining this channel, and common if it carries information for several mobiles. An associated control channel is allocated to one mobile, in addition to a dedicated channel, and carries signaling for the operation of this channel.

Table 2.1 summarizes the purpose of the different logical channels. In this table, UL stands for uplink and DL for downlink.

	Logical Channel	Abbreviation	UL/DL	Task
Broadcast Channel(BCH)	Broadcast Control Channel	BCCH	DL	System Information broadcast
	Frequency Correction Channel	FCCH	DL	Cell frequency synchronization
	Synchronization Channel	SCH	DL	Cell time synchronization and identification
Common Control Channel	Paging Channel	PCH	DL	MS paging
	Random Access channel	RACH	UL	MS random access
	Access Grant Channel	AGCH	DL	Resource allocation

	Cell Broadcast Channel	CBH	DL	Short messages broad cast
Dedicated Control Channel	Standalone Dedicated Control Channel	SDCCH	UL/DL	General signaling
	Slow Associated Control Channel	SACCH	UL/DL	Signaling associated with the TCH
	Fast Associated Control Channel	FACCH	UL/DL	Handover signaling
Traffic Channel	Full speech	TCH/FS	UL/DL	Full-rate voice channel
	Half rate	TCH/HS	UL/DL	Half-rate voice channel
	2.4 Kbps, 4.8 Kbps, 9.6 Kbps, and 14.4 Kbps full-rate data channels	TCH/F2.4 TCH/F4.8 TCH/F9.6 TCH/F14.4	UL/DL	Full-rate data channels
	2.4-Kbps- and 4.8-Kbps-rate data channels	TCH/H2.4 TCH/H4.8	UL/DL	Half-rate data channels

Table 2.1: The logical channels and their purpose [9]

2.6.3 TDMA Time Structure

In GSM systems, the basic time unit is the time slot with a duration of 576.9µs = 15/26ms, or 156.25 symbol periods; a symbol period is 48/13µs. The piece of information transmitted during a time slot is called a burst. The GSM multiple access scheme is TDMA, with eight time slots per carrier. A sequence of eight time slots is called a TDMA frame, and has duration of 4.615 ms; the time slots of a TDMA frame are numbered from 0 to 7, as shown in Figure2.2. Note that the beginning and end of TDMA frames in uplink and downlink are shifted in time: Time slot number 0 on the uplink corresponds to time slot 3 in the downlink. This allows some time for the mobile to switch from one frequency to the other.

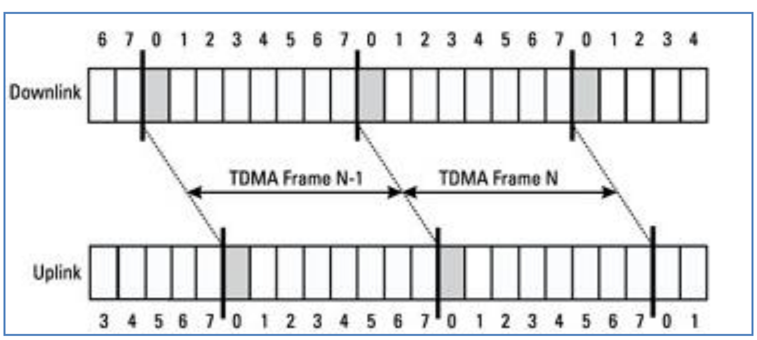


Figure2.3 Slot numbering within the TDMA frame [8]

The GSM system distinguishes between traffic channels (used for user data) and control channels (reserved for network management messages). The Traffic Channel/Full-Rate Speech (TCH/FS) is used to carry speech at 13 kbps.

TCHs for the uplink and downlink are separated in time by 3 burst periods, so that the mobile does not has to transmit and receive simultaneously. TCHs are defined using a 26-frame multi frame (i.e. a group of 26 TDMA frames). The length of a 26-frame multi-frame is 120 ms, which is how the length of a burst period is defined (120 ms / 26 frames / 8 burst periods per frame). Out of the 26 frames, 24 are used for traffic, one is used for the Slow Associated Control Channel (SACCH) and one is currently unused.

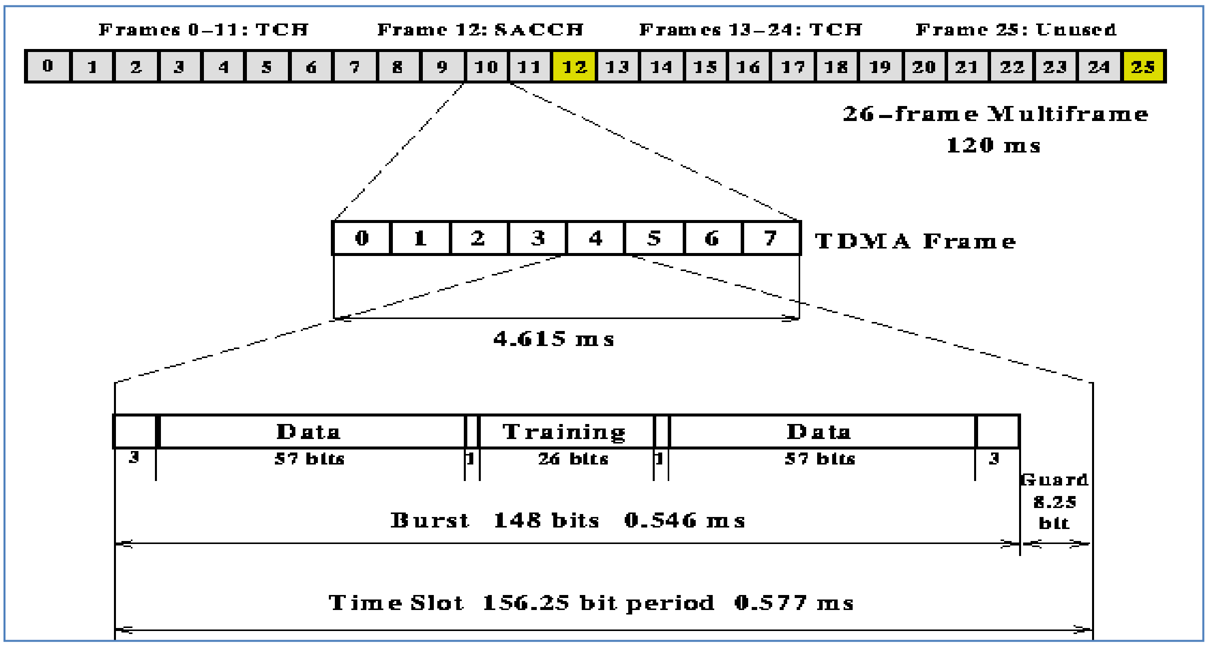


Figure2.4The TDMA frame structure [10]

GSM slot is the smallest individual time period that is available to each mobile. It has a defined format because a variety of different types of data are required to be transmitted. Although there are shortened transmission bursts, the slot is normally used for transmitting 148 bits of information. This data can be used for carrying voice data, control and synchronization data.

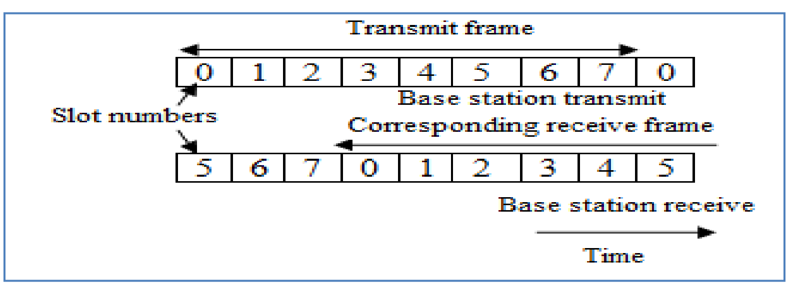


Figure2.5: GSM slot offset between transmit and receive [11]

It can be seen from the GSM slot structure that the timing of the slots in the uplink and the downlink are not simultaneous, and there is a time offset between transmit and receive. This offset in the GSM slot timing is deliberate and it means that a mobile that which is allocated the same slot in both directions does not transmit and receive at the same time. This considerably reduces the need for expensive filters to isolate the transmitter from the receiver. It also provides a space saving.

2.6.4 GSM Burst Types

The GSM burst, or transmission can fulfill a variety of functions. Some GSM bursts are used for carrying data while others are used for control information. As a result of this a number of different types of GSM burst are defined.

2.6.4.1 GSM Normal Burst

This GSM burst is used for the standard communications between the base station and the mobile, and typically transfers the digitized voice data. The structure of the normal GSM burst is exactly defined and follows a common format. It contains data that provides a number of different functions [11]:

1. **3 Tail Bits**: These tail bits at the start of the GSM burst give time for the transmitter to ramp up its power
2. **57 Data Bits**: This block of data is used to carry information, and most often contains the digitized voice data although on occasions it may be replaced with signaling information in the form of the Fast Associated Control Channel (FACCH). The type of data is indicated by the flag that follows the data field
3. **1 Bit Flag**: This bit within the GSM burst indicates the type of data in the previous field.
4. **26 Bits Training Sequence**: This training sequence is used as a timing reference and for equalization. There are a total of eight different bit sequences that may be used, each 26 bits long. The same sequence is used in each GSM slot, but nearby base stations using the same radio frequency channels will use different ones, and this enables the mobile to differentiate between the various cells using the same frequency.
5. **1 Bit Flag**: Again, this flag indicates the type of data in the data field.
6. **57 Data Bits**: Again, this block of data within the GSM burst is used for carrying data.
7. **3 Tail Bits:** These final bits within the GSM burst are used to enable the transmitter power to ramp down. They are often called final tail bits, or just tail bits.
8. **8.25 Bits Guard Time**: At the end of the GSM burst there is a guard period. This is introduced to prevent transmitted bursts from different mobiles overlapping. As a result of their differing distances from the base station.

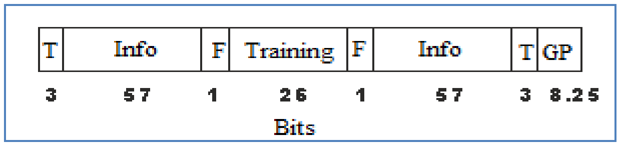


Figure2.6: GSM Normal Burst

2.6.4.2 GSM Synchronization Burst

The purpose of this form of GSM burst is to provide synchronization for the mobiles on the network.

1. **3 Tail Bits**: Again, these tail bits at the start of the GSM burst give time for the transmitter to ramp up its power
2. **39 Bits of Information**
3. **64 Bits of a Long Training Sequence**
4. **39 Bits Information**
5. **3 Tail Bits**: Again these are to enable the transmitter power to ramp down.
6. **8.25 Bits Guard Time**: To act as a guard interval.

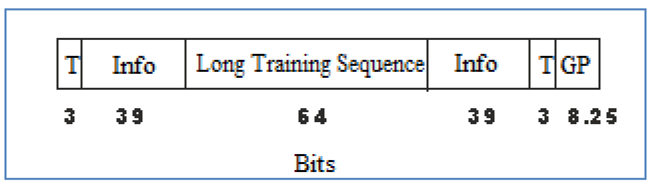


Figure2.7: GSM Synchronization Burst

2.6.4.3 GSM Frequency Correction Burst

With the information in the burst all set to zeros, the burst essentially consists of a constant frequency carrier with no phase alteration.

1. **3 Tail Bits**: These tail bits at the start of the GSM burst give time for the transmitter to ramp up its power.
2. **142 bits all set to zero**
3. **3 Tail Bits:** These are to enable the transmitter power to ramp down.
4. **8.25 Bits Guard Time**: To act as a guard interval.

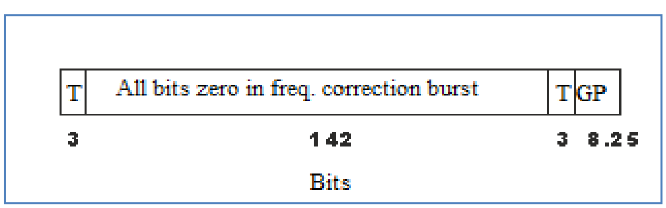


Figure2.8 GSM Frequency Correction Burst

2.6.4.4 GSM Random Access Burst

This form of GSM burst used when accessing the network and it is shortened in terms of the data carried, having a much longer guard period. This GSM burst structure is used to ensure that it fits in the time slot regardless of any severe timing problems that may exist. Once the mobile has accessed the network and timing has been aligned, then there is no requirement for the long guard period.

1. **7 Tail Bits**: The increased number of tail bits is included to provide additional margin when accessing the network.
2. **41 Training Bits**:
3. **36 Data Bits**:
4. **3 Tail Bits**: Again these are to enable the transmitter power to ramp down.
5. **69.25 Bits Guard Time**: The additional guard time, filling the remaining time of the GSM burst provides for large timing differences.

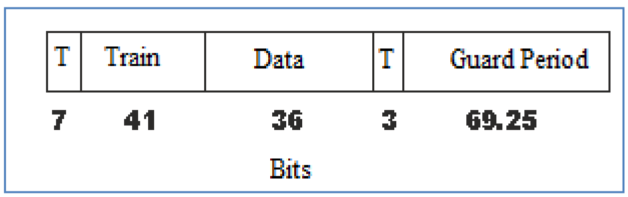


Figure2.9: GSM Random Access Burst

2.6.5 Frequency Hopping Capability

The frequency hopping capability is optionally used by the network operator on all or part of its network. The main advantage of this feature is to provide diversity on one transmission link (especially to increase the efficiency of coding and interleaving for slowly moving mobile stations) and also to average the quality on all the communications through interferer's diversity. It is implemented on all mobile stations [13].

The principle of slow frequency hopping is that every mobile transmits its time slots according to a sequence of frequencies that it derives from an algorithm. The frequency hopping occurs between time slots and, therefore, a mobile station transmits (or receives) on a fixed frequency during one time slot (=577μs) and then must hop before the time slot on the next TDMA frame. Due to the time needed for monitoring other base stations the time allowed for hopping is approximately 1ms, according to the receiver implementation. The receiving and transmitting frequencies are always duplex frequencies.

The frequency hopping sequences are orthogonal inside one cell (i.e. no collisions occur between communications of the same cell), and independent from one cell to a homologue cell (i.e. using the same set of RF channels, or cell allocation). The hopping sequence is derived by the mobile from parameters broadcast at the channel assignment, namely, the mobile allocation (set of frequencies on which to hop), the hopping sequence number of the cell (which allows different sequences on homologue cells) and the index offset (to distinguish the different mobiles of the cell using the same mobile allocation). The non-hopping case is included in the algorithm as a special case. The different parameters needed and the algorithms are specified in GSM 05.02. In case of multi band operation frequency hopping channels in different bands of operation, e.g. between channels in GSM and DCS, is not supported. Frequency hopping within each of the bands supported shall be implemented in the mobile station.

It must be noted that the basic physical channel supporting the BCCH does not hop.

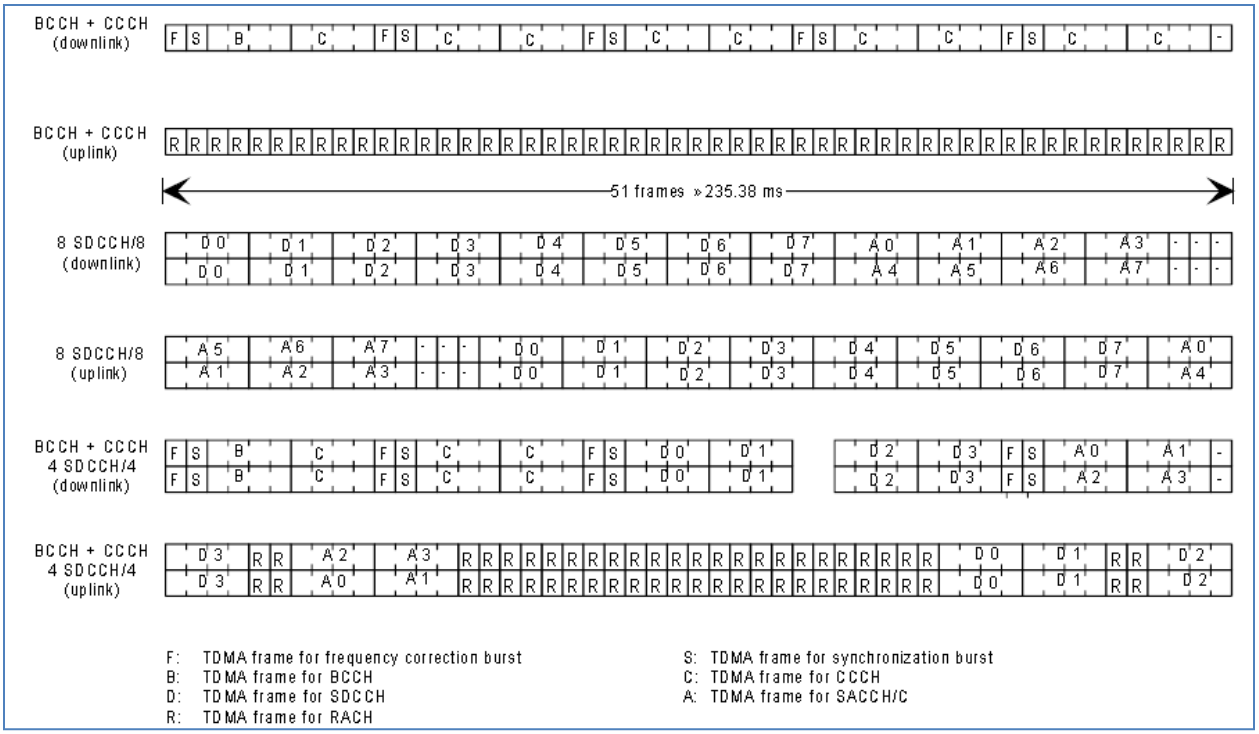


Figure2.10: Channel organization in the 51-frame multi-frame [13]

2.7 GSMR Network Architecture

A GSMR mobile communication network is composed of several function entities. The function collection of each entity can provide basic services and supplementary services to GSMR network users. GSMR communication network architecture is based on GSM structure, which is mainly formed by three major systems, including Mobile Station (MS), Base Station System (BSS) and Network Switching System (NSS).

BSS is mainly formed by Base Station Controller (BSC) and Base Transceiver Station (BTS). BSS provides the connection between NSS and ME, which is in charge of the transmission and reception. BTS, an important part for direct feelings of customers, handles the radio interface to the MS. BSC controls a group of BTSs and manages their radio resources. BSC is in charge of handoffs, frequency hopping, exchange functions and power control over each managed BTSs.

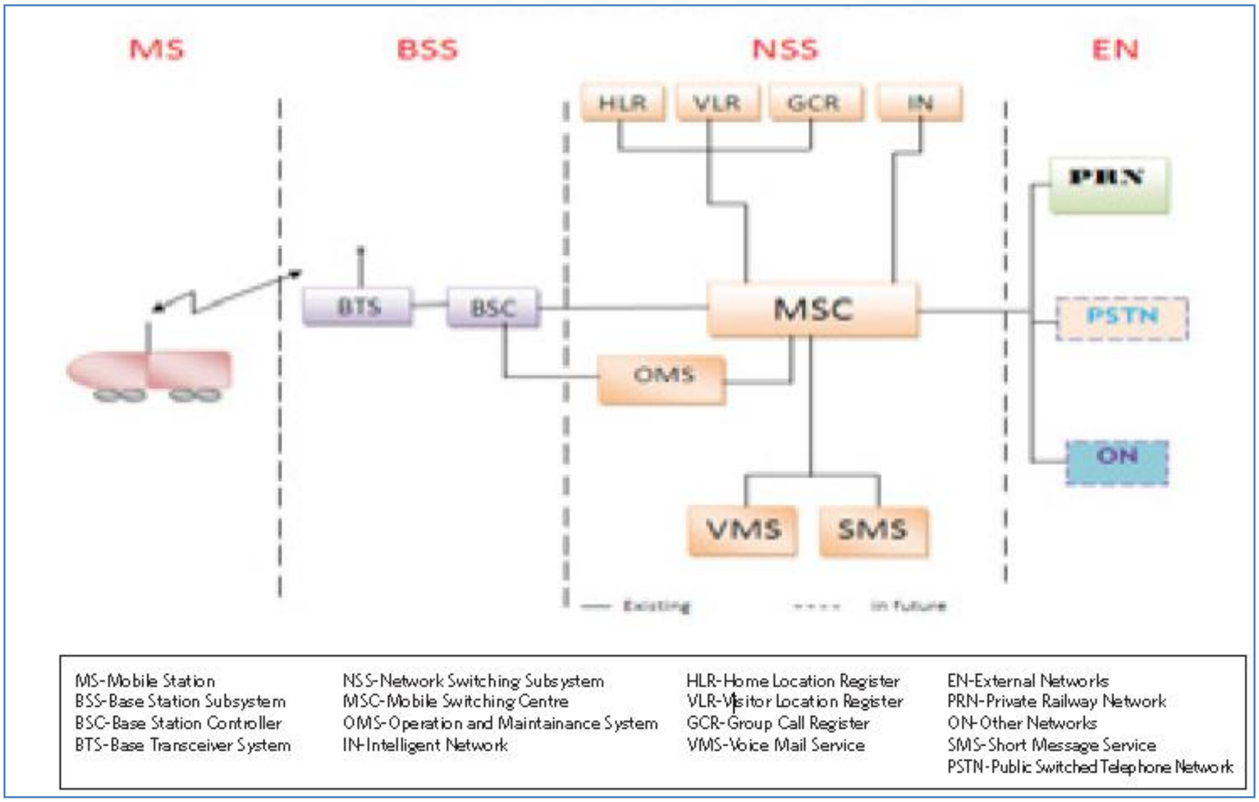


Figure2.11: Simplified GSMR architecture [14]

NSS is generally formed by six function entities, Mobile Services Switching Center (MSC), Home Location Register (HLR), Visitor Location Register (VLR), Authentication Center (AUC), Equipment Identity Register (EIR) and Group Call Register (GCR). NSS plays a key role on managing the communications between the mobile users. It also can realize some other functions, such as user data management, mobility management and fixed network connection. MSC is the core of NSS, which sets up and releases the end-to-end connection, handles mobility and hand-over requirements during the call.

VLR is connected with MSC, which is the database to store temporary information about roaming subscribers. HLR stores the data of Individual Subscriber Authentication Key for each SIM. AUC stores the data about the International Mobile Subscriber Identity (IMSI) the Subscriber Authentication key, and the defined algorithms for encryption. EIR, which maintains a list of all valid terminals as identified by their IMEI, stores the information about security-sensitive of the mobile equipments. As the specific part of GSMR system, GCR stores various information such as the group ID, the group call area ID, the group call referenced information whether the call is active or not, etc.

Chapter Three

3. Radio Network Planning for Awash-Woldia Rail Line

The main aim of radio network planning is to provide a cost effective solution for the radio network deployment in terms of coverage, capacity and quality such as estimating the optimum number of base stations and its location, determining the type of the antenna, the receiver /transmitter power and the environment characteristics of the propagation environment. The radio network planning process and design criteria vary from place to place depending up on the dominating factor, which could be capacity or coverage.

The RAN planning can be divided into different phases. Since the steps are mostly overlapping and can be done hand-in-hand, most literatures had followed the planning assumptions of GSMR to be having three main steps.

- Initial phase: this includes collection of pre-planning information and starting network dimensioning.
- Nominal Cell Planning:
- Final Cell Planning:
- Optimization:

When GSMR service deployment planning is done, a number of tasks need to be performed to achieve the optimum service performance in terms of coverage, capacity and quality.

3.1 Introduction to GSMR Network Planning

What makes network planning different for GSMR, are basically three things. First of all, the requirements are much more specific. That makes sense if you think about it. That is the quality of service of your phone conversation drops in a certain area; generally your safety is not affected. But if your GSMR signal is unreliable, even for a few meters, results can be catastrophic. Secondly, the initial network design of GSMR includes a division of group call areas. When a train encounters a problem, GSMR is used to send information to the control center. But it can also send direct commands to other trains in the vicinity. One such command could be 'Stop!' So, it is crucial that group call areas are properly defined, which is also done in the initial network design.

Thirdly, traditional radio planners never have to worry about these sorts of things. But the main reason why GSMR radio planning is a different ball game altogether is a technical one. Traditionally, in theory at least, antennas are placed in hexagons: that is the most efficient way to cover an area. But GSMR is not meant to cover a large, two dimensional spaces, but rather a line from point A to point B. This is why the focus of a GSMR radio network planner is completely different [16].

This research work assumes GSMR deployment through the Awash-Woldia rail line. The line is assumed to suburban considering future population density, constructions, the scale of existing and future infrastructure and the geographic location of the stations.

The new Awash-Woldia railway project is an extension project that will connect to Addis Ababa-Djibouti railway line. Awash railway station lies along the railway line from Addis Ababa to Djibouti. The 389km-long single railway line will start from the north east of Awash and progress northwards through Kombolcha to reach Woldia.

The Awash-Woldia railway line will involve the construction of 389Km of new rail line, 40km maintenance lines and 18km station lines. It also includes construction of new tunnels, four main stations with two platforms, and six intermediate/sub stations with a single platform. The total length of the railway line will thus be 447Km. When it begins an operation, 6 for freight and 20 for passengers, in total 26 trains will be in operation.

Based on the total length of the line, we determine the number of base stations needed for coverage. From the traffic/number of trains to be entertained in the line, we provide an estimate of the expected number of users and their data density requirements.

Element	Value
Main Stations	4
Sub Stations	6
Number of Freight Trains	6
Number of Passenger Trains	20
Total Line Rail Length	447 km
Number of Estimated Active MSs	1500(Approximated)

Table 3.1 Demographics of Awash-Woldia Line

After defining the traffic model of the line of interest, the step that follows involves determining the technological parameters to calculate cell coverage and capacity. Parameters of interest include link budget, spectral efficiency, and antenna configurations. These altogether defines the coverage area, cell site and the total number of base stations needed to cover the desired geography.

3.2 Coverage Planning

Coverage Planning is the first step in the process of dimensioning. It gives an estimate of the resources needed to provide service in the deployment area with the given system parameters, without any capacity concern. It gives an assessment of the resources needed to cover the area under consideration, so that the transmitters and receivers can listen to each other.

Radio network planning mainly depends on geographical and morphological data. Thus, a basic coverage may always be calculated with existing models using digital maps of the respective area. This models need to be tuned for railway environment and to achieve a high location probability.

Network coverage is calculated based on the path-loss data between the base stations and users as well as using antenna configuration parameters such as antenna type, power, radiation characteristics, tilt and azimuth.

3.2.1 Propagation Models

Coverage area is an area of extent to which the radiated signal is covered. A cellular network is a radio network distributed over land areas called cells, each served by at least one fixed-location transceiver known as a cell site or base station. These cells joined together provide radio coverage over a large geographic area. This radio network makes large number of portable transceivers, like mobile phones, to communicate with each other.

The cell coverage depends on the environment and it differs according to the environment. The environments are Urban, Sub-urban and Rural. The three main mechanisms which are the causes for the reduction in the cell coverage are reflection, diffraction and scattering.

There are two ways in which radio planners can use propagation models. They can use their own model or they can use the existing standard models. The empirical models use existing equations obtained from results of several measurement efforts. Some of the path loss models are as follows. The most common models used in GSMR are:

- Okumura-Hata Model
- COST 231-Walfish-Ikegami

3.2.1.1 Okumura-Hata Model

The Okumura-Hata model has been developed depending on extensive measurements done by Okumura in and around Tokyo, Japan. This model is the most widely used one in wireless communications for predicting the behavior of electromagnetic waves in built up areas. This model incorporates the basic information from Okumura and develops it further to realize the effects of diffraction, reflection and scattering caused by different structures. And also this model has formulas for suburban and rural areas. Okumura-Hata model defines the path loss as follows:

$$PL(dB) = 69.55 + 26.16\log(f_c) - 13.82\log(h_b) - a(h_m) + [44.9 - 6.55\log(h_b)]\log(d) + C \tag{3.1}$$

Where d is the distance between the transmitter and the receiver in Km, f_c is given in MHz, h_b is the height of the transmitter's antenna in meters (the antenna of the base station, BS), and h_m is the height of the receiver's antenna in meters (the antenna of the mobile station or train antenna, MS). The function $a(h_m)$ and the factor C depend on the environment:

- Small and medium-size cities:

$$a(h_m) = (1.1\log(f_c) - 0.7)h_m - (1.56\log(f_c) - 0.8) \qquad 3.2a$$

$$C = 0 \qquad 3.2b$$

- Metropolitan areas:

$$a(h_m) = \begin{cases} 8.29 log(1.54h_m)^2 - 1.1 & for\ f \le 200MHz \qquad 3.3a \\ 3.2\ log\ (11.75h_m)^2 - 4.97 & for\ f \ge 400MHz \qquad 3.3b \end{cases}$$

- Suburban environments:

$$a(h_m) = (1.1\log(fc) - 0.7)h_m - (1.56\log(f_c) - 0.8) \qquad 3.4a$$

$$C = -2[\log(f_c/28)]^2 - 5.4 \qquad 3.4b$$

- Rural area:

$$a(h_m) = (11.1\log(fc) - 0.7)h_m - (1.56\log(f_c)) - 0.8 \qquad 3.5a$$

$$C = -4.78[\log(f_c)]^2 + 18.33\log(f_c) - 40.98 \qquad 3.5b$$

Table 3.2 gives the range in which the model is valid. It is noteworthy that the parameter range

Parameters	Symbol	Range
Carrier frequency	f_c	150-1500MHz
Effective BTS antenna height	h_b	30-200m
Effective MS antenna height	h_m	1-10m
Distance	d	1-20 Km

Table 3.2: Range of validity for the Okumura-Hata model

Table 3.2 gives the range in which the model is valid. It is noteworthy that the parameter range does not encompass the 1,800-MHz frequency range most commonly used for second and third generation cellular systems. This problem was solved by the COST 231-Hata model, which extends the validity region to the 1,500-2,000 MHz range by defining:

$$PL(db) = A = 46.3 + 33.9\log(f_c) - 13.82\log(h_b) - a(h_m) + [44.9 - 6.55\log(h_b)]\log(d) + C \qquad (3.6)$$

Where, $a(h_m)$ is defined in equation (3.5) C is 0 in small and medium-sized cities, and 3 in metropolitan areas.

3.2.1.2 The COST 231-Walfish-Ikegami Model

The COST 231 model is a path-loss model when small distances exist between the MS and BS, and/or the MS has a small height. The total path-loss for the line of sight (LOS) case is given by:

$$PL = 42.6 + 26\log(d) + 20\log(f_c) \tag{3.7}$$

for 20 m ≤ d ≤ 5000 m, where again d is in units of kilometers, and fc is in units of MHz. For the NLOS case, path-loss consists of the free space path-loss L_0, the multi-screen loss L_{msd} along the propagation path, and attenuation from the last roof edge to the MS, L_{rts} (rooftop-to-street diffraction and scatter loss):

$$PL = \begin{cases} L_0 + L_{msd} + L_{rts} & for\ L_{msd} + L_{rts} \geq 0 \\ L_0 & for\ L_{msd} + L_{rts} \leq 0 \end{cases} \tag{3.8}$$

The free space path loss L_0 is given by:

$$L_0 = 32.4 + 20\log(d) + 20\log(f_c) \tag{3.9}$$

Ikegami derived the diffraction loss L_{rts} as:

$$L_{rts} = -16.9 - 10\log(w) + 10\log(f_c) + 20\log(\Delta h_m) + L_{ori} \tag{3.10}$$

where w is the width of the street in meters, and $\Delta h_m = h_{roof} - h_m$ is the difference between the building height h_{roof} and the height of the MS as shown in Figure3.1.

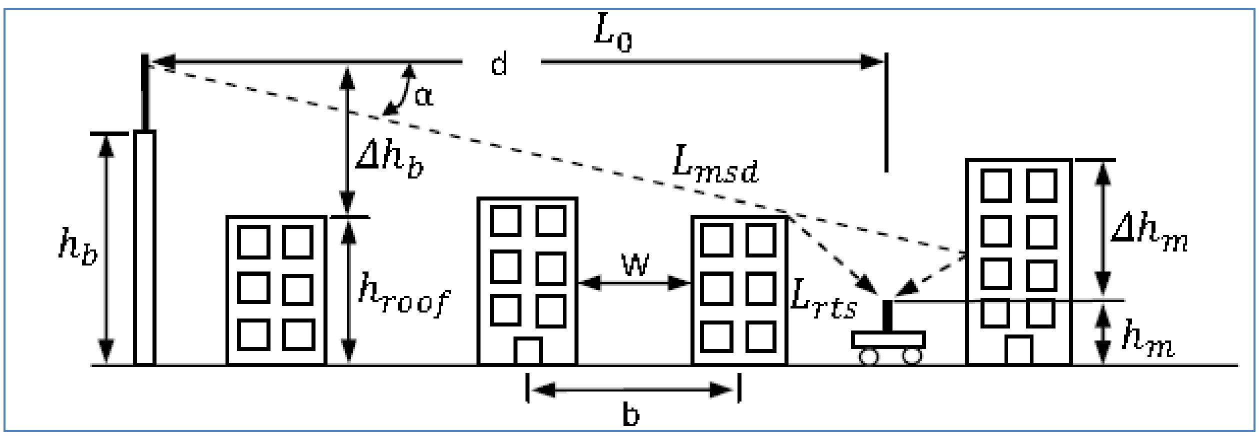


Figure3.1: Parameters in the COST 231-Walfish-Ikegami model

The orientation of the street affects the path loss. This effect is taken into account by the correction factor L_{ori}:

$$L_{ori} = \begin{cases} -10 + 0.543\varphi & for\ 0^0 \leq \varphi \leq 35^0 \\ 2.5 + 0.075(\varphi - 35) & for\ 35^0 \leq \varphi \leq 55^0 \\ 4 - 0.114(\varphi - 55) & for\ 55^0 \leq \varphi \leq 90^0 \end{cases} \tag{3.11}$$

where φ is the angle between the street orientation and the direction of incidence in degrees. For the computation of the multi-screen loss L_{msd}; building edges are modeled as screens. The multi-screen loss is then given as [24]:

$$L_{msd} = L_{bsh} + k_a \log(d) + k_f \log(f_c) - 9\log(b) \tag{3.12}$$

Where b is the distance between two buildings (in meters), and:

$$L_{bsh} = \begin{cases} -18\log(1+\Delta h_b) & for \quad h_b > h_{roof} \\ 0 & for \quad h_b \leq h_{roof} \end{cases} \tag{3.13}$$

$$k_a = \begin{cases} 54 & for\ h_b > h_{roof} \\ 54 - 0.8\Delta h_b & for\ d \geq 0.5km\ and\ h_b \leq h_{roof} \\ 54 - \dfrac{0.8\Delta h_b d}{0.5} & for\ d < 0.5km\ and\ h_b \leq h_{roof} \end{cases} \tag{3.14}$$

$$k_d = \begin{cases} 18 & for\ h_b > h_{roof} \\ 18 - \dfrac{15\Delta h_b}{h_{roof}} & for\ h_b \ \leq h_{roof} \end{cases} \tag{3.15}$$

$$k_f = -4 + \begin{cases} 0.7\left(\dfrac{f_0}{925} - 1\right) & for\ medium\ size - cities\ and\ suburban\ areas \\ & with\ average\ vegtion\ density \\ 1.5\left(\dfrac{f_0}{925} - 1\right) & for\ metropolitan\ areas \end{cases} \tag{3.16}$$

Where, $\Delta h_b = h_b - h_{roof}$, and h_b is the height of the BS. Table 3.2 gives the validity range for this model.

Parameters	Symbol	Range
Carrier frequency	f_c	800-2000MHz
Effective BTS antenna height	h_b	40-50m
Effective MS antenna height	h_m	1-3m
Distance	d	0.02-5 km

Table3.3: Range of validity for the COST 231-Walfish-Ikegami model.

The following equation summarizes the loss equation for the COST 231-Walfish-Ikegami model.

$$PL = 32.4 + 20\log(f) + 220\log(d) + L_{trs} + L_m \quad (3.17)$$

where L_{rts} and L_m are the rooftop to street diffraction and scatter factor and multi-screen loss, respectively.

3.2.2 Propagation Model Selection

The selection of a suitable radio propagation model for GSMR is of great importance. A radio propagation model describes the behavior of the signal while it is transmitted from the transmitter towards the receiver. It gives a relation between the distance of transmitter and receiver, and the path loss. From this relation, one can get an idea about the allowed path loss and the maximum cell range. Because of the rail line in consideration is suburban considering future cases, the COST 231-Walfish-Ikegami model is less comparable as a result of its range is limited for short and mostly urban plans. Also, after running a numerical simulation of these two propagation models, the results are plotted as shown in Figure3.2. For the purposes of this numerical simulation (and others that follow), we will consider the entire Awash-Woldia rail line as suburban line. Other assumptions include a BTS height of 30 m, mobile station antenna height of 4 m and frequency 900MHz.

The frequency selection is done by comparing the theoretical characteristics of the two GSMR frequency bands (900 MHz, 1800 MHz) like capacity, propagation power requirement, propagation characteristics and line topography with the characteristics of the line in consideration. So we have got 900 MHz band is the better band for the Awash-Woldia rail line.

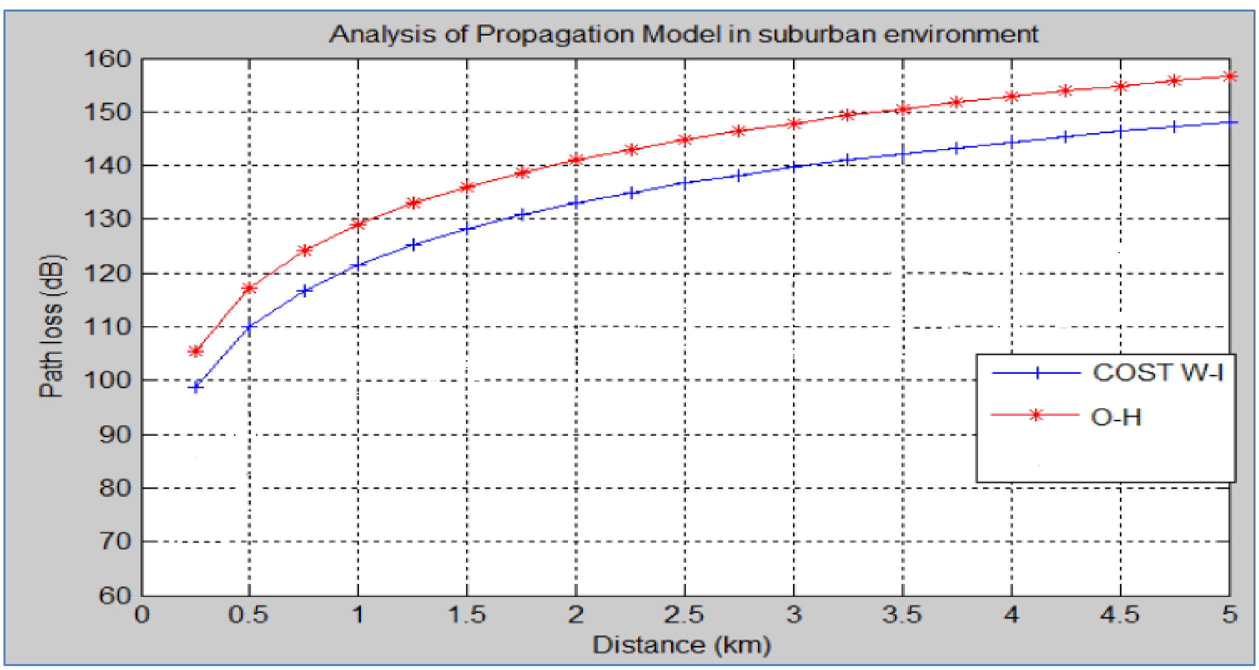


Figure3.2 Path loss comparison

Details of the GSMR RF performance and system parameters can be found in 3GPP technical specification 3GPP TS 45.005[0]. The main GSMR system characteristics are summarized in Table3.4.

From simulation results shown in Figure3.2, the maximum path loss is obtained in Okumura-Hata propagation model. From a planning perspective, it is better to assume worst case scenarios so as to avoid risking an inadequate coverage. Hence, the Okumura-Hata model is chosen in this thesis work to develop the radio network planning.

3.2.3 Link Budget Calculation

A link budget is the sum and total of all gains and losses in the radio connection between two parties from end to end; including antennas, feed lines and the path between the antennas, but also the relevant portions of the transmitter and the receiver, as well as miscellaneous gains and losses.

Link budget calculation is used to determine the maximum allowable path loss (MAPL). MAPL is the link margin we get when we subtract all the loss parameters from the sum of our gain parameters. The path loss at any given point in our intended coverage area needs to be less than or equal to this link margin.

Parameters	Downlink	Uplink	Notes
Max. transmit power	30 dBm	2 dBm	a
Transmit antenna gain	18 dBi	0	b
Transmitter losses	3 dB	0	c
EIRP	**45 dBm**	**2 dBm**	**d=(a+b-c)**
Channel bandwidth	4 MHz	4MHz	e
Receiver antenna gain	0	18 dBi	f
Receiver losses	2 dB	2 dB	g
Receiver noise figure	5 dB	9 dB	h
Thermal noise	-121 dBm	-121 dBm	i=kTB
Required SINR	6 dB	10dB	j
Receiver sensitivity	-110 dBm	-102 dBm	k=(h+i+j)
Fade margin	9 dB	9 dB	l
Max. path loss	**146 dB**	**111 dB**	**m=(d+f-g-k-l)**

Table3.4 Link Budget [19]

3.2.4 Cell Radius Calculation

The maximum cell radius of base stations can be determined based on the selected propagation model (Okumura-Hata) and using the maximum allowable path loss (MAPL) obtained from link budget calculation.

The resulting MAPL for a mobile handheld device would equate to 146 dBm in the uplink and 111 dBm in the downlink (see Table 3.4). From the value of the MAPL for the UL cases (since range is limited by the uplink transmission rather than the downlink due to constraints on power and antenna gain of MSs) it is possible to predict the coverage range using the Okumura-Hata propagation model; and on an average a cell radius of a single CU will equate to 11.14 Km.

3.2.5 Determining the Number of CUs

The GSMR base station (CU) connects the BSC to the mobile stations (MSs), and therefore it is an important metric in determining the coverage of the network and end-users experience.

In other radio technologies like UMTS and public GSM, based on the cell radius, we can determine the coverage area of a single base station. The coverage area of a single base station leads into determining the total number of base stations required to cover a particular region in a given metropolitan area. But in GSMR this approach is not acceptable, because the coverage is not about an area, it is about a line. If we would to do so it is wastage. In addition, due to the continuous change (heading direction) of rail route, it is not possible to predict the total number of CUs needed to cover a given route knowing the coverage range of a single BTS. This is because as the route changes its direction, no more service from a nearby site; a new site oriented to that route is needed. Therefore, the number of CUs is known always after simulation by fulfilling all coverage requirements.

3.3 Capacity Planning

GSMR capacity planning is a complex task. As the GSMR service becomes developed, the requirement on network capacity changes. In GSMR capacity planning, planners must consider the multiple factors; including point-to-point call, group call, broadcast call, data service, and subscriber number.

Railway network traffic models differ from those in public mobile networks. Subscribers will have more BHCA, SCI and even a longer talk time. Applications like ETCS even will require a

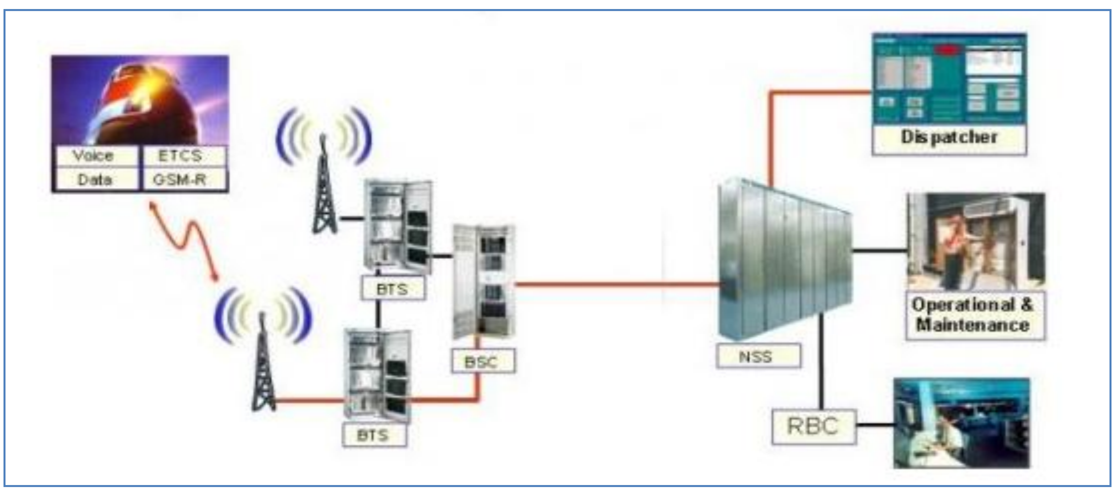


Figure3.3 Simplified GSMR system [23]

traffic channel over the full journey of a train. In turn the number of subscribers is pretty low in comprise with PLMN. Features like ASCI VGCS or VBS will have an impact to the traffic model. Based on the technical design by ERC, we made a typical traffic model of the Awash-Woldia rail line as shown in Figure3.6.

3.3.1 Factors limiting the system capacity

3.3.1.1 Limited Availability of Speech/Data Channels in a Cell

In the air-gap, a circuit switched connection is used. This means from the start till it reaches its destination, a train continuously occupies a data channel for services like GPS for example. There is limited number of available frequencies, 19, and as a consequence of this, limited number of available speech and data channels, 7 per frequency. This is the limitation of the system when the requirement is that there is always one channel available for each moving train. The GSMR system is using a cell concept for coverage and best usage of the limited number of frequencies. As we can see in the Figure3.4 below it is possible to cover a line with just two frequencies.

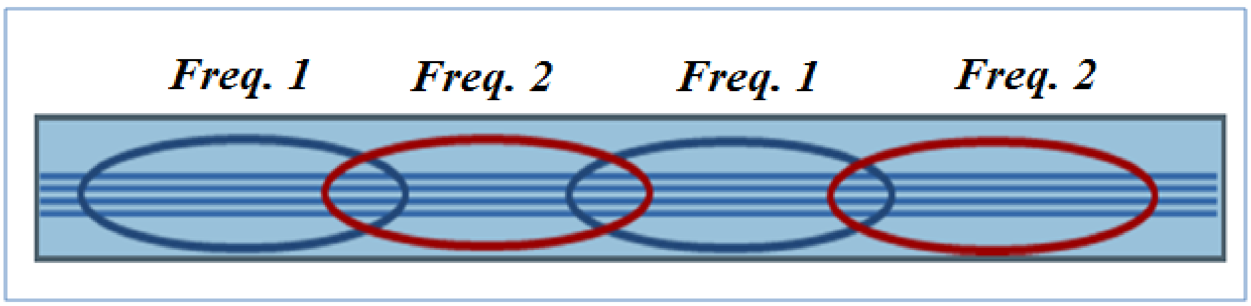


Figure3.4 GSMR track line coverage with two different frequencies

This will provide 7 speech/data channels and can be considered as a minimum configuration. The configuration is unreliable; if one cell not be properly working the train will be forced to stop.

3.3.1.2 Cell Planning on Areas with High Density of Trains

Cell planning on a high speed line means large cells covering long stretches of the line, as there are few trains moving in the cells at the same time. This means that the cell hand-over to the next cell takes up to 10 seconds, and a train moving in 350 km/h runs close to a kilometer in that time. There can be a need for more channels when double or quadruple track is used. Still, when using Level 2 with fixed blocks with one train per block on the same time, there should not be more need of available channels than can be covered by one or two TRX, i.e. 7 or 14 channels.

On a station or a railway yard there are often more than one train or moving units in a dense area standing still or moving slowly. There might be railway staff dealing with switching that requires more speech traffic than out on the line. On a small station with one or two main tracks and a few side tracks for marshalling, this is not a problem. One factor to consider though is that if trains are passing the station in high speed the cell size must consider the hand-over area.

On a large station or large marshalling yard, there are many movements on a rather dense area, but in low speed. It is therefore a need to have many small cells that can handle many calls in a limited area.

Finally, when congested situations or other abnormal situations like severe weather conditions or accidents occur, the normal line for high speed conditions might turn into a ‘parking place for trains’. Where there is normally one or two trains in the same cell, there might be an increased number of trains, which also has an increased usage of speech channels.

3.3.1.3 Interference with Other Mobile Systems

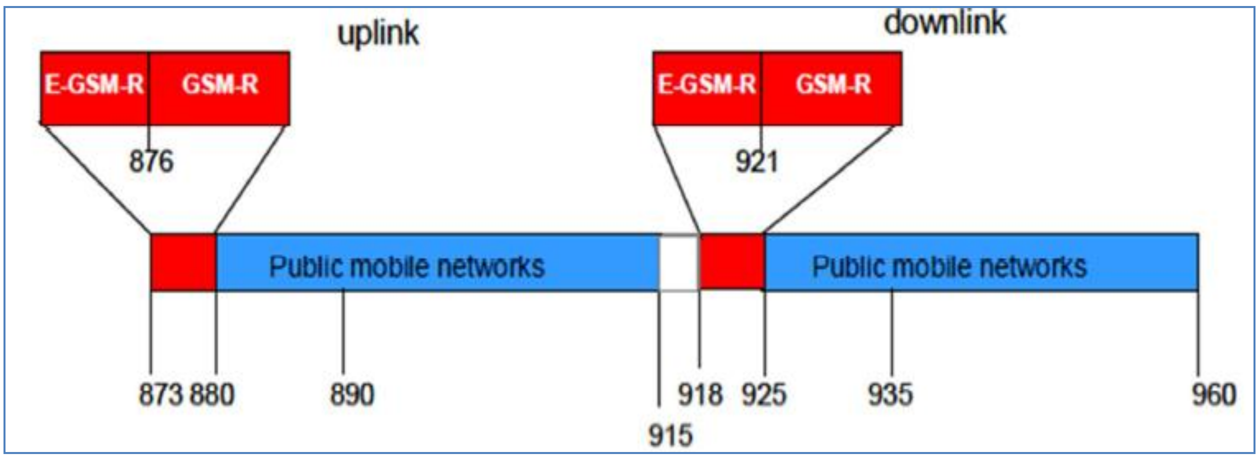


Figure3.5 GSMR frequency overview [15]

GSMR is working in a reserved spectrum in the 900 MHz band. Close to that, other public mobile service providers operate GSM systems as well as the subsequent third and fourth generation mobile systems like UMTS, WiMAX and LTE.

As the public mobile operators sometimes has cell coverage close to or overlapping the GSMR cell and also with a higher field-strength, there is a risk of interference and severe disturbance of the GSMR traffic. At the ERA GSMR Conference in October 2011 [22], it was reported that this problem is identified at over 400 locations in Europe, and that the size of such locations could be from a few meters up to a few hundred meters.

The disturbance decreases or makes it impossible to use the GSMR connection in the disturbed location. This results in failed transmission, which causes the train to stop, jammed traffic, delays and bad performance of the network. Railway emergency calls can be affected, an even higher risk for casualties.

3.3.1.4 Internal Transmission Systems Limitations

In the transmission chain between the RBC and the EVC in the moving unit there are many different protocols and interfaces to pass. If any conversion is made, it has to be ensured that the correctness of the data is guaranteed, as well as the capacity. The needed capacity is not very high, but the requirement on reliability is very high.

The bottleneck in the system is the air-gap. The bit rate of 9.6 kbps is enough, but the number of channels is limited. A limiting factor is that the wireless transmission system, as all such systems, has a need for internal signaling according to the common channel signaling principle. Of the 8 available speech/data channels per TRX, one is used for this purpose. One signaling channel can be used for two TRX making 15 channels available, but for security reasons two signaling channels can be used for one TRX as well, making only 6 channels usable. A useful compromise between reliability and capacity is 2 signaling channels for 3 TRX, making a total of 22 channels for data/voice traffic.

3.3.2 Observations and Cause of Interference

Recently some GSMR operators have noticed operational limitations caused by interferences to their networks from public mobile networks emissions. The majority of cases of GSMR issues described so far are only involving GSM systems. Regarding the coexistence with wideband systems such as UMTS and LTE, interferences from UMTS900 to GSMR have been reported in a limited number of cases [15].

The analysis of different measurement campaigns confirms that both blocking and inter-modulation effects from public mobile networks (GSM) affect the operational performance of GSMR service. It turned out that current GSMR mobile stations are impacted by blocking and inter-modulation effects when the interfering radio emissions exceed a signal level of around -40 dBm. This is consistent with the blocking or inter-modulation levels defined in ETSI EN 301 502 for the first GSM channel.

Interference cases were observed for both low and high GSMR received signal strength. Some of the observed interferences may not be assigned to blocking and/or inter-modulation, thus other effects, like wide-band noise have to be considered as possible sources.

The relevant mechanisms by which interfering transmitters affect receivers are receiver desensitization, receiver blocking and receiver overload. Receiver desensitization can be caused by different sources such as [15]:

- unwanted emissions transmitted from various interferers
- IMP generated in the receiver - in particular 3rd and 5rd order IMPs - increasing the receiver noise floor.
- Power leakage from interfering signals due to limited receiver selectivity.

In order to avoid a significant increase of the receiver noise floor causing receiver desensitization, unwanted emissions and IMPs should be sufficiently below the affected receiver noise floor.

3.3.3 GSMR International Public Roaming

The International Public Roaming function makes it possible also for GSMR subscribers from abroad to make use of this service in other visited GSMR networks away from their home one and yet to use the latter's telecommunication functions with the same mobile end device and SIM card.

By enabling also the use of a public mobile-telephone network in dedicated situations and locations, the availability of the railway's GSMR network can be very significantly broadened for subscribers in the respective country. These services in the home network can now also be offered for subscribers from other GSMR networks, provided appropriate switching has been set up in those networks and the necessary agreements concluded. International Roaming makes it possible for GSMR subscribers to move outside of their home network, to login and to update their location in other GSMR networks and to use all the GSMR functions there.

One technical prerequisite for setting up roaming is the existence of an interconnection between the mobile network switching centers (MSCs). If no direct connection exists between two GSMR roaming-partner networks, it is possible, as an alternative, to build one up by transiting through other GSMR networks. Another prerequisite is that the addresses of all network elements in the GSMR networks and their interconnections must be set up in the databases of each of the central MSCs [25].

In many cases, it does not make either technical or economic sense to roll out GSM-R installation to such extent that the last rarely-trafficked railway lines, peripheral tracks or other railway installations, as well as industrial railways or private sidings would be covered. The possibility for the use of a Public Mobile-Telephone network by GSMR subscribers from the same country of origin is known as National Public Roaming and gives access to the selected public GSM networks for domestic GSMR users. It will be readily understood that it does not work the other way round for public subscribers of P-GSM services.

3.3.4 Available Frequencies and Channels

In General, dedicated frequencies are reserved by European Conference of Postal and Telecommunications Administrations (CEPT) for the use of GSMR for operational communications by railway companies. For uplink communication 4 MHz is reserved in the 876 – 880 MHz band, and for downlink 4 MHz in the 921 – 925 MHz band. As these frequencies are agreed on a European basis, they allow border crossing and international traffic. The 4 MHz for GSMR makes 19 frequency channels of 200 kHz each available. One of the frequency channels, F20 is used as guard band. On a national basis the frequencies in the extended, E-GSMR, band can be used. The E-GSMR band is a 3 MHz slot in uplink 873 – 876 MHz and 918 – 921 MHz downlink. This makes another 15 frequency channels available. This band is not yet used [20].

Each 200 kHz frequency channel has 8 timeslots available to be used as data or voice channels, whereof one is used as the common control channel for the radio system (this concept is called Common Channel Signaling and is used for the internal control of the radio transmission system), and the remaining 7 are used for voice or data communication. One control channel can be used for two frequency channels, making 7 + 8 =15 timeslots/channels available for communication.

To ensure the high levels of Quality of Services (QoS) it is stated that circuit switched connection shall be used for ETCS messages. This means that there is a continuous connection set between the base station and the moving unit, ensuring a high QoS. But it is not a very efficient usage of the connection, as the amount of data exchanged is rather low.

Instead of circuit switching, packet switching can be used. In this case more than one user shares the same connection and the information transmitted is split up in packages sent each one after another, and only when there is a need for it. This is a more efficient way to use the available media, up to 7 times more efficient than a circuit switched connection. The concept is used in GSMR for non ETCS data applications with GPRS technology.

3.3.5 Defining Capacity in GSMR

3.3.5.1 Capacity Related to the Number of Trains

The capacity of this system can be defined as how many moving units in a specified area the system can control at the same time. The area can be a fixed block or any other type of limited geographical area.

Other definitions of 'capacity' in a railway system are used, for example passenger kilometers per time unit, tones per time unit, weight or volume per meter track. These definitions are depending on other factors than the signaling system, even if the number of trains handled can be an important part of it. In this work, four cases for considering the signal capacity can be identified:

- Single track line
- Double or multiple track line
- Small yard, i.e. main track and one or two sidings
- Large yard, marshalling yard, large passenger terminal

3.3.5.2 Capacity Related to Data Messages

Due to the fact that the radio connection for data transmission shall be based on the circuit switched principle, a moving train is continuously connected via GSMR on the whole journey from A to B, not only when messages are sent. The amount of data sent on this continuous connection is very low. A position update message consists of 14 bytes and a movement authority message to the train is between 40 to 500 bytes, average 250 bytes.

As an example, if one position updates message and one movement authority message is sent every single minute, 14x8 + 250x8=2.112 bits are sent during this minute. The transmission speed is 9.600 bits per second, which equals to 576.000 bits that is possible to send during this minute. The usage is then 0.4 % of the available capacity.

3.3.5.3 Capacity Related to Available Data and Voice Channels

The available 7 timeslots for one GSMR frequency is the minimum for a cell. They can be used for both voice and data; in that way the capacity is shared between data and voice calls. If needed, more frequencies and thereby timeslots can be allocated to one cell.

The telecom traffic is studied in the science of traffic theory, and a short summary of it shall be made here. Telecom traffic is measured in Erlang and the definition is that a call lasting 1 hour is equal to 1Erlang. 30 calls lasting 2 minutes each is also equal to 1Erlang.

The traffic is described in traffic models that can be used to calculate the need of telecom lines or in this case radio channels during the busiest hour, accepting a decided level of congestion or rejected calls. There are different formulas for the calculations; one of the most common is the Erlang formula, which appears in three different varieties depending on how rejected calls are handled. The Erlang B formula implies that a rejected call is lost, in Extended Erlang B formula a given percentage of calls immediately make a new attempt, and in the Erlang C formula, a rejected call queues up until it can be handled. The amount of voice traffic varies; in the case of disturbance and in shunting yards, the volume can be rather high, occupying 3 to 4 channels for that use. On the other hand, the calls are of this nature short and used to exchange more or less formal orders and information.

3.3.6 Subscriber Number Estimation

In this section, an approach for estimating the data density requirements to meet specific subscriber needs is discussed. Arriving at an accurate estimate of capacity requirements for new radio services is not a simple task. We must anticipate how users will make use of the new services being offered and how often users will use the network. Since we do not have an existing data to base our estimate on (as the service is new to that specific area), we must make use of reasonable guess and estimation as is the general technique used for first time deployment.

Traffic-Source	Call Type	Bandwidth
Train Radio	Voice	9.6kbps
Emergency Phones	Voice	9.6kbps
Maintenance people	Voice	9.6kbps

Station Personnel	Voice	9.6kbps
Shunting Radio	VGCS(Voice)	9.6kbps
Broadcast Calls	VBS(Voice)	9.6kbps
Fixed subscribers	Voice(Voice)	9.6kbps
ETCS	Data	20kbps
Ticket Machines	Data	20kbps
Train Diagnostic	Data	20kbps

Table 3.5 GSMR Common Services

Prior to calculating the data density requirement, the operator needs to decide the data rate assigned to individual users (of all types) during the busiest hour of the day. In order to estimate the required data density per end user for the regions of interest, the peak busy hour (PBH) activity level has to be defined or assumed by the operator. Users mix (percentage distribution of customers among the category of users) is other parameter that is used in combination with the PBH activity level to determine the minimum per end user rate.

Traffic-Source	Traffic Mix	PBH	Minimum data rate during PBH
ETCS	15%	15%	675kbps
Ticket Machines	5%	15%	225kbps
Train Diagnostic	10%	15%	450kbps
Data Density Requirement in PBH			1.35Mbps

Table 3.6: Estimated peak busy hour data requirement

Assuming a normal dimensioning value for traffic per user of 30mErl during the network busy hour [21], **578** voice service subscribers create a traffic **of 578 × 30mErl** = **17.34Erl**. Therefore for traffic of **17.34**Erl assuming an average duration of 5 minutes for each call and delay probability of 0%, the resulting number of voice calls according to Erlang formula is approximately **208**.

Assuming a codec with **9.6Kbps bit** rate for voice calls, **208 calls** would require a data rate of **2Mbps**. We already have a data density requirement of **1.35Mbps** (Table3.6).Therefore, the expected traffic on the access gateway (aGW) will be **2 Mbps** for voice services and **1.35Mbps** for data services. This equates **3.35Mbps** overall data rate requirement for the entire **447Km** long Awash-Woldia rail line.

Chapter Four

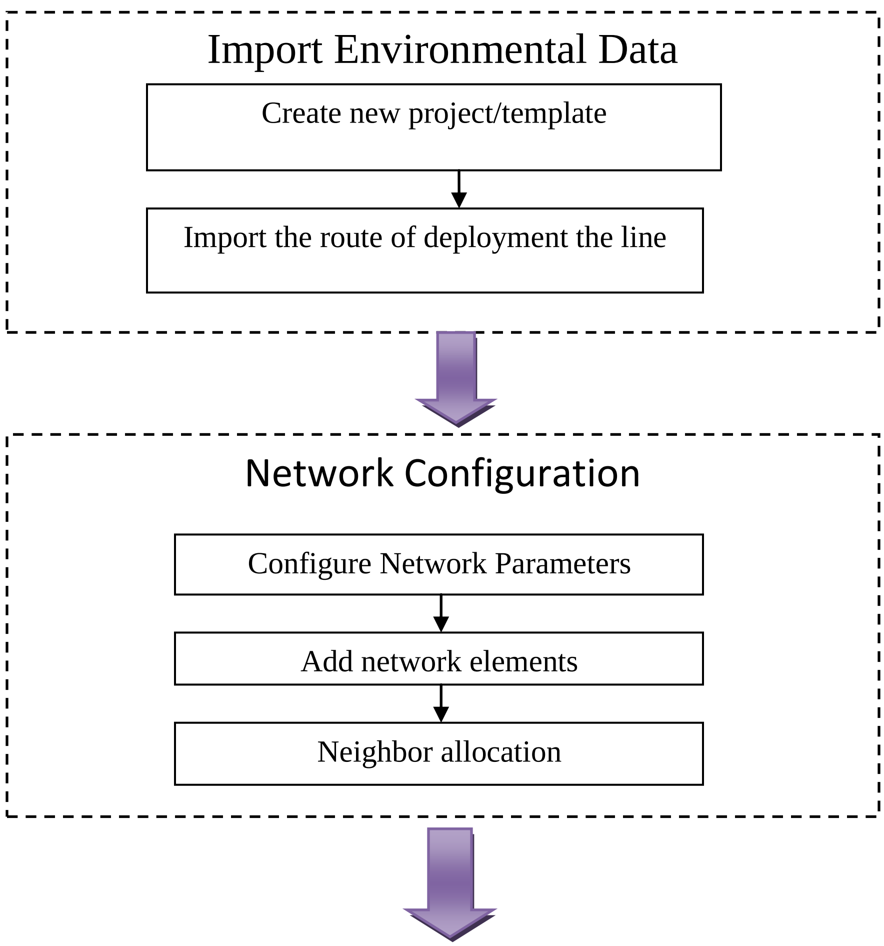
4. Simulation Results and Analysis

In this chapter we will discuss the simulation results done based on Atoll radio network planning tool.

In this thesis, simulation is used to investigate the RAN nominal planning of GSMR networks as it is done using Atoll simulation environment. In most cases, the radio link budget calculation can simply be done using different tools like Excel for their simplicity and availability. However, in this thesis Atoll was chosen as simulation environment for its in-depth input analysis and flexible working environment.

4.1 Designing GSMR Network Using Atoll

The structure and flow of the simulation for both coverage and capacity evaluation is shown in Figure4.1. It will be discussed in the following sections as how the coverage planning is done; and the performance is evaluated.



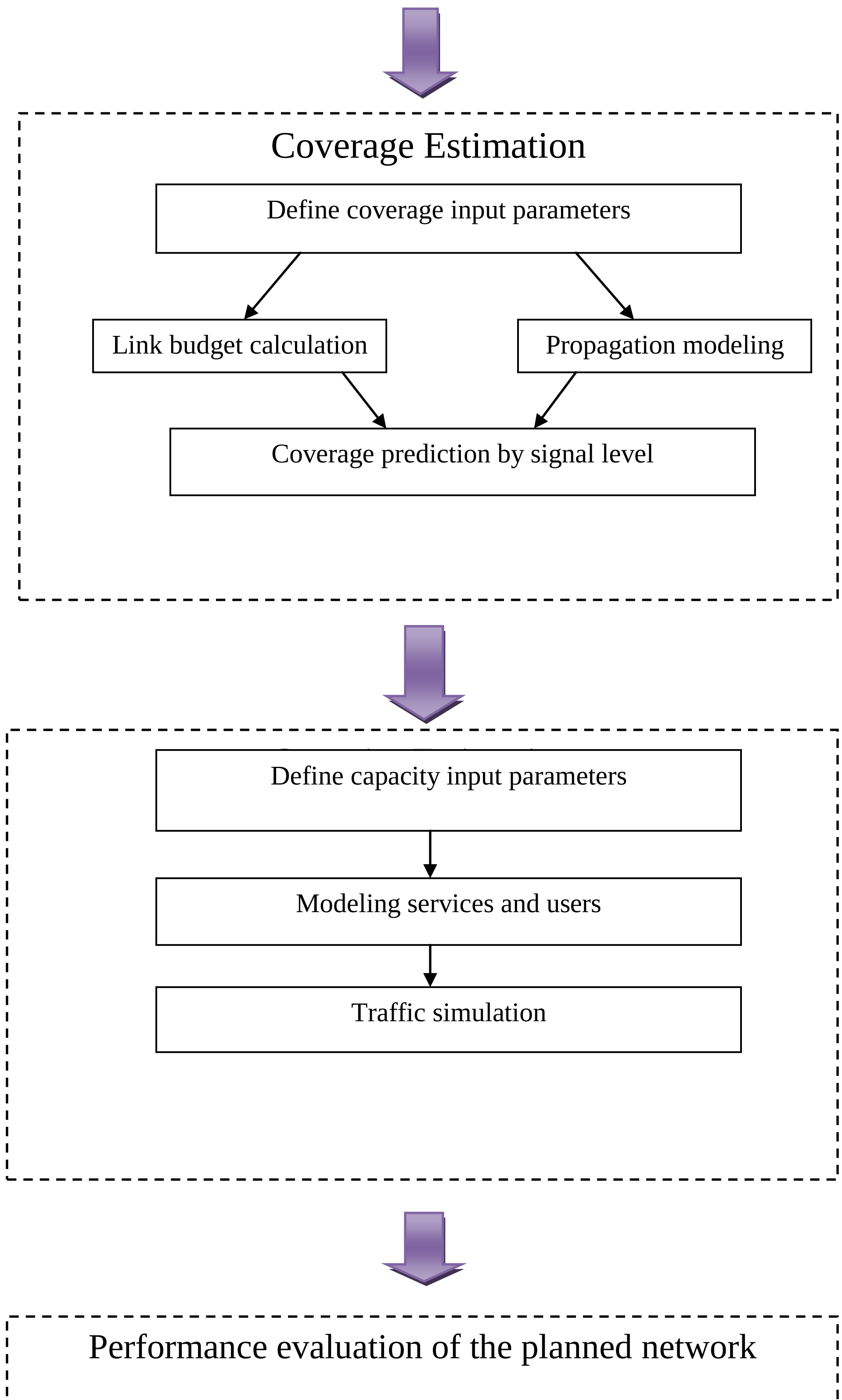
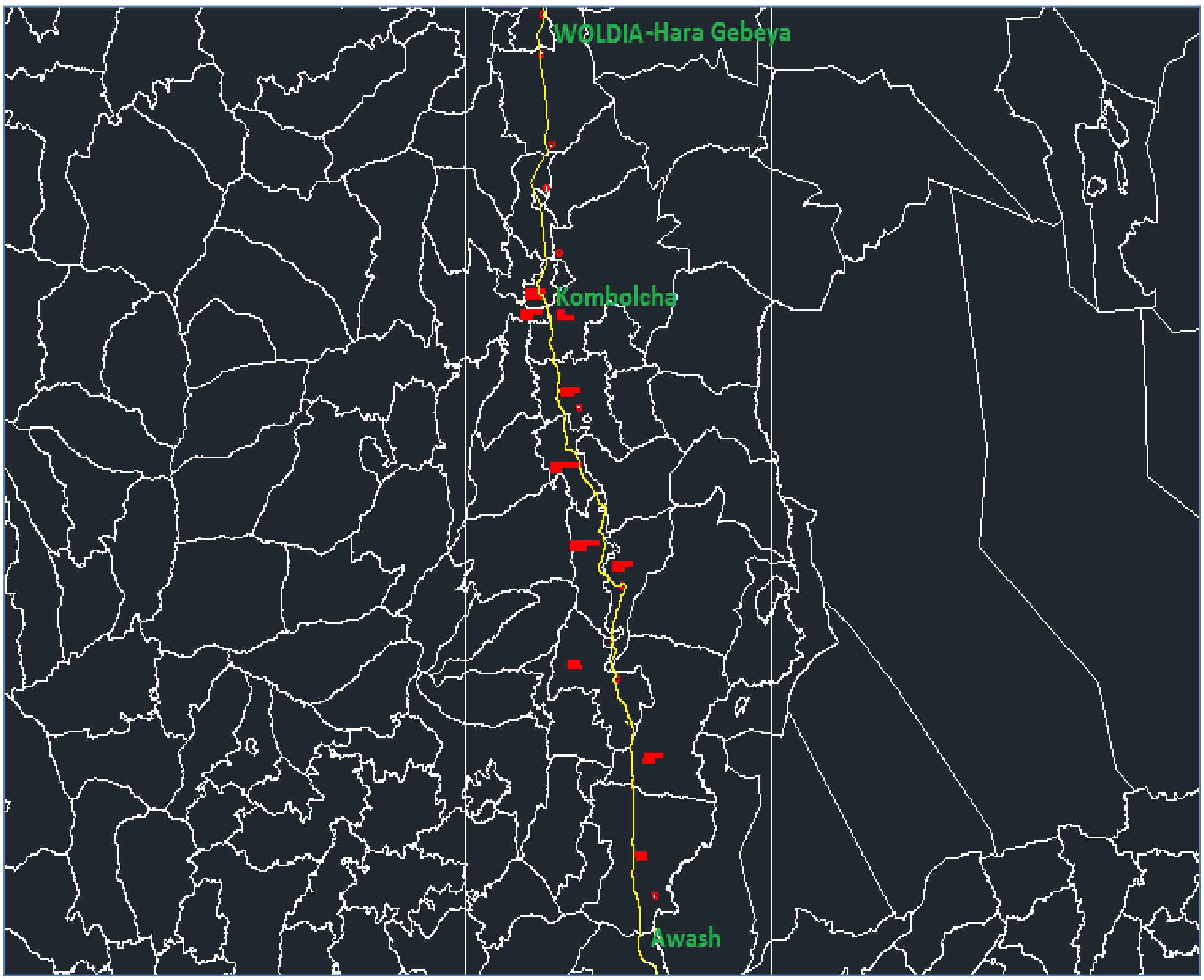


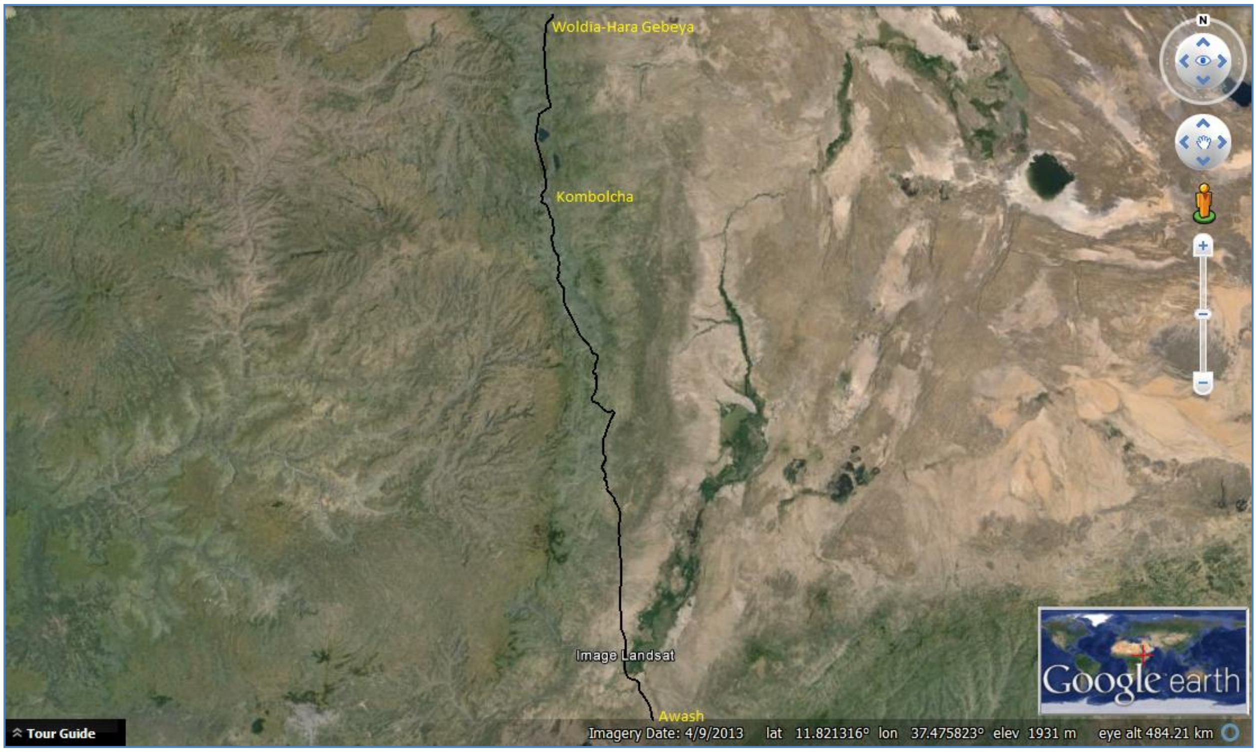
Figure4.1: Flow chart for GSMR network planning using Atoll

We can create an Atoll document from a template, with no base stations, or from a database with an existing set of base stations. In Atoll, a site is defined as a geographical point where one or more transmitters are located. Once we have created a site, we can add transmitters. A transmitter is defined as the antenna and any additional equipment.

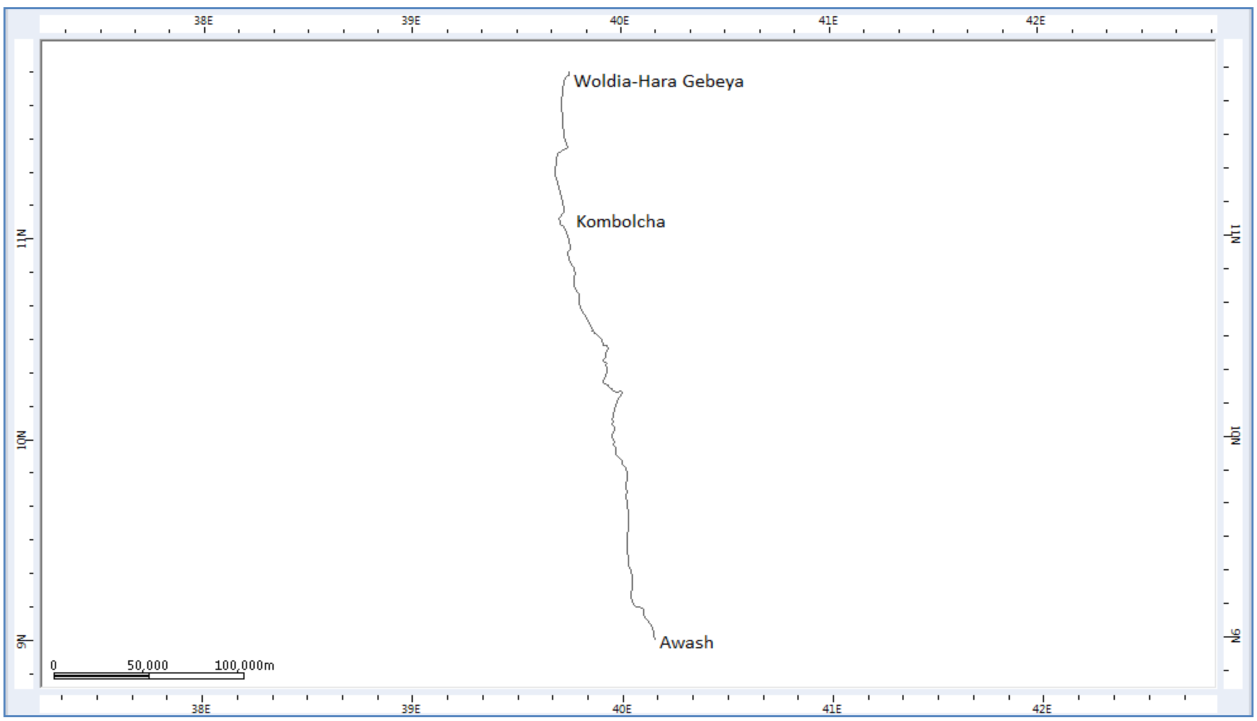
In this thesis work Google Earth plays a significant role in identifying the topographic nature of the route of interest; especially for identifying what the terrain topography throughout the line is. No other environmental data is used in the simulation of this work. This is because we couldn't find any form of digital data from Ethiopia map Agency for the route or any place along. So we enter the route to Atoll and inspect the topography of the line by exporting the work to Google Earth digital map. The AutoCAD drawing and equivalent Google Earth map shown in Figure4.2 (a) and (b) has been used for radio network planning in this stage.



(a)AutoCAD



(b) Google Earth



(c) Atoll

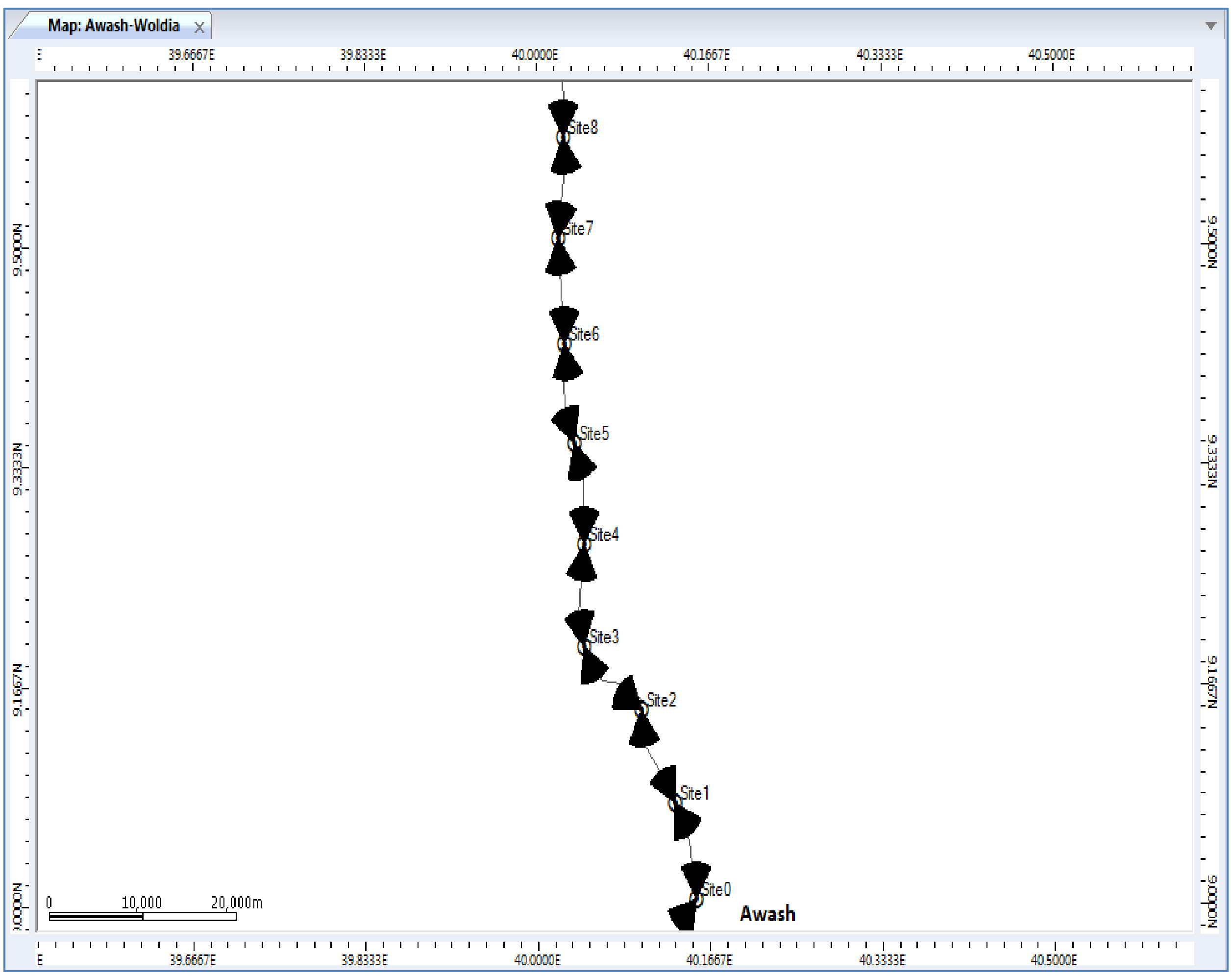
Figure4.2 Awash-Woldia rail line route

4.2 Coverage Prediction

In Atoll, we can study a single base station or a group of base stations using coverage predictions. Atoll allows us to make a variety of coverage predictions, such as signal level and signal quality coverage predictions. The results of calculated coverage predictions can be displayed, compared, and studied on the map, Google Earth in our case.

Atoll enables you to model network traffic by creating services, users, user profiles, traffic environments, and terminals. This data can be then used to make coverage predictions that depend on network load, service area, and radio bearer throughput coverage predictions.

At first to cover the whole Awash-Woldia line, 40 BTSs were placed as shown partially in Figure4.3. This number of BTSs comes from the coverage and capacity analysis performed in section 2.4 and 3.2. The number of BTSs is increased after optimization as the route is not a straight line; which needs another site as it changes direction from the serving direction of another site.



(a) Atoll

(b) Google Earth

Figure4.3: Sites placed in Awash-Woldia rail line

After placing the BTSs, coverage prediction was done that helped to justify the placement of BTSs looking to the nature of the route in Google Earth as in Figure4.4. After optimization 8 BTSs are added to the first calculated 40 BTSs. A signal level coverage prediction displays signal level of best server BTS for each pixel of the area studied.

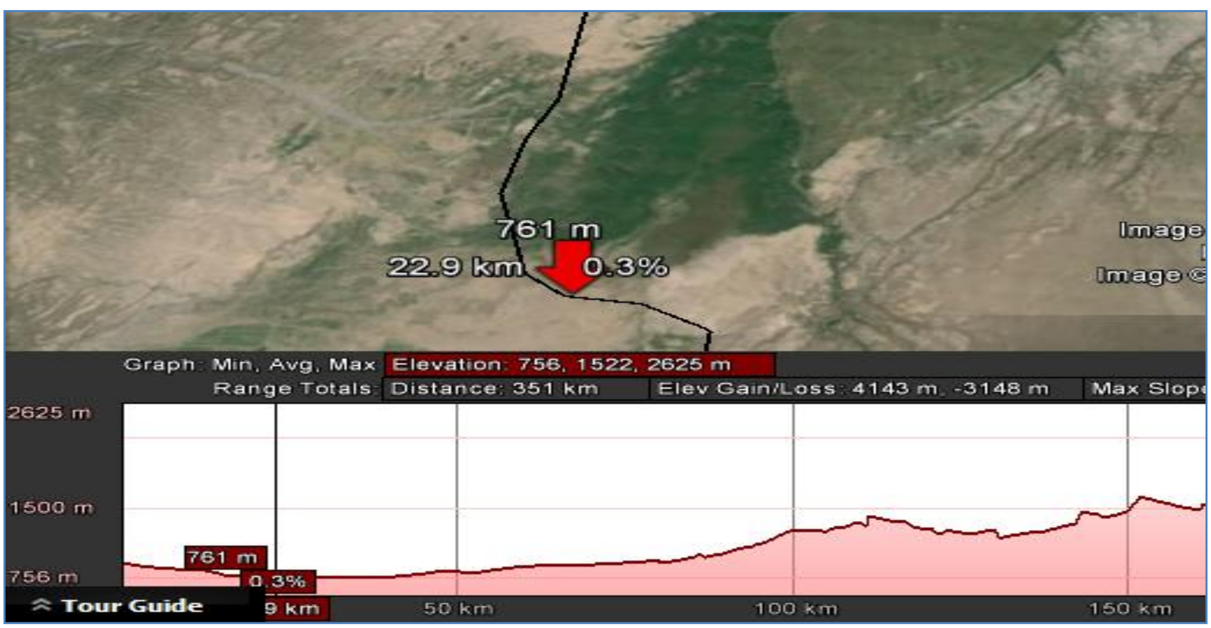


Figure4.4: Elevation profile of route (sample)

A separate table shows the simulation properties for each of the simulated traffic maps. Legends show each of them with different color. Figure4.5 shows the prediction properties for each of the best signal level with different colors.

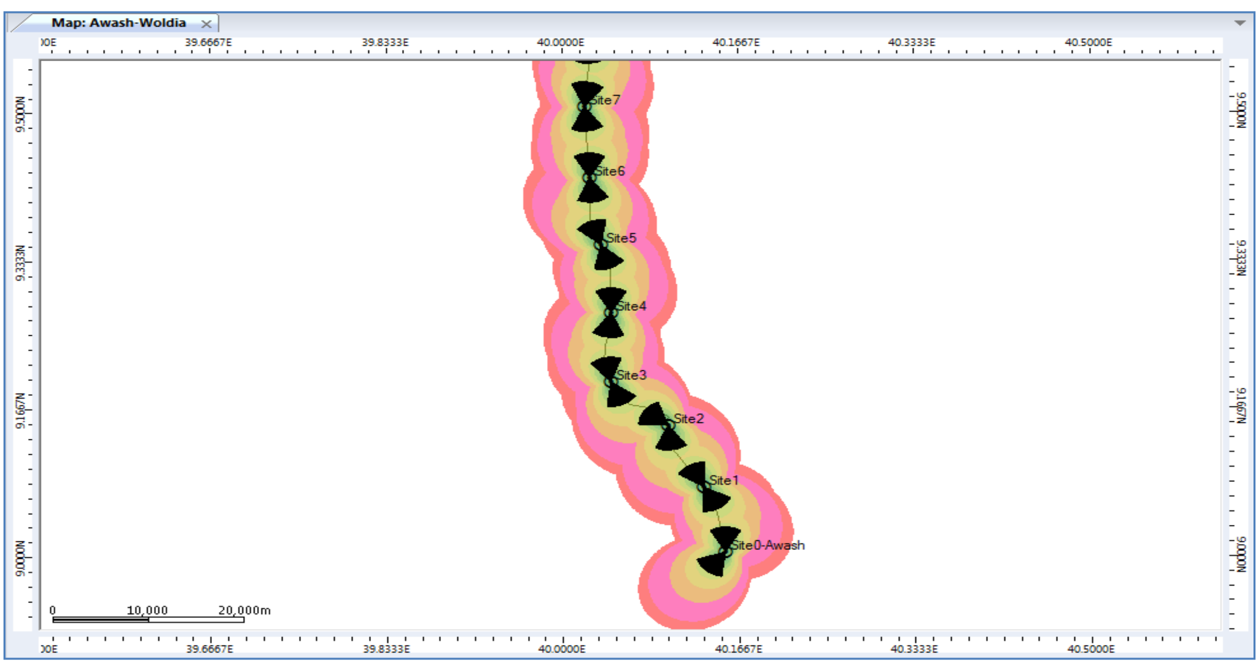
Display type: Value intervals
Field: Best Signal Level (dBm)

		Min	Max	Legend
1		-70		Best Signal Level (dBm) >=-70
2		-75		Best Signal Level (dBm) >=-75
3		-80		Best Signal Level (dBm) >=-80
4		-85		Best Signal Level (dBm) >=-85
5		-90		Best Signal Level (dBm) >=-90
6		-95		Best Signal Level (dBm) >=-95
7		-100		Best Signal Level (dBm) >=-100
8		-105		Best Signal Level (dBm) >=-105

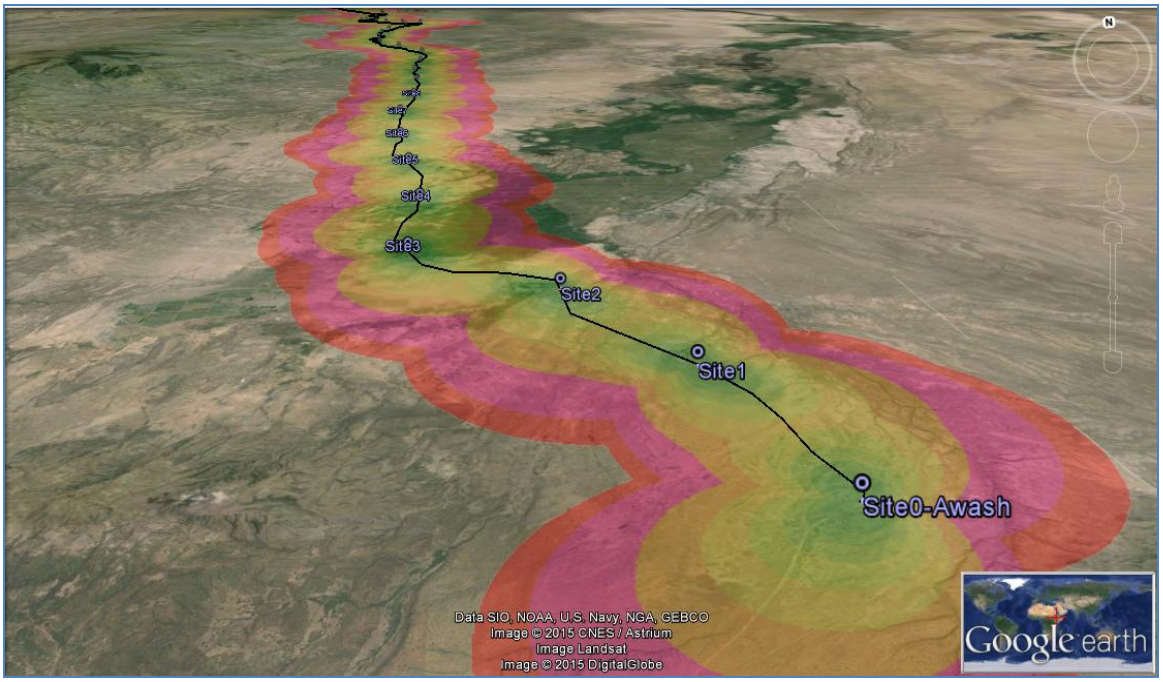
Figure4.5: Coverage prediction properties

In any RF planning simulation, we must assign a propagation model. 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 the only input for the propagation model as a parameter is distance. But in order to have the effect of the terrain, Google Earth view of the route is used.

Any coverage prediction made on a base station uses the propagation model to calculate its results. Figure4.6 shows coverage predictions performed by signal level. The coverage of each 48 BTSs is indicated by different colors according to the received signal level measured in dBm.



(a) Atoll



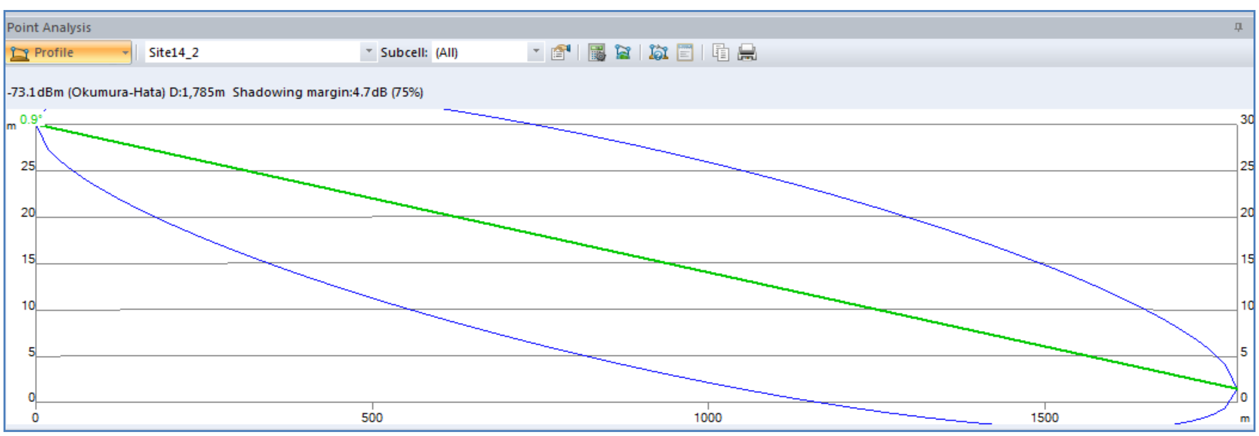
(b) Google Earth

Figure4.6: Coverage prediction by signal level

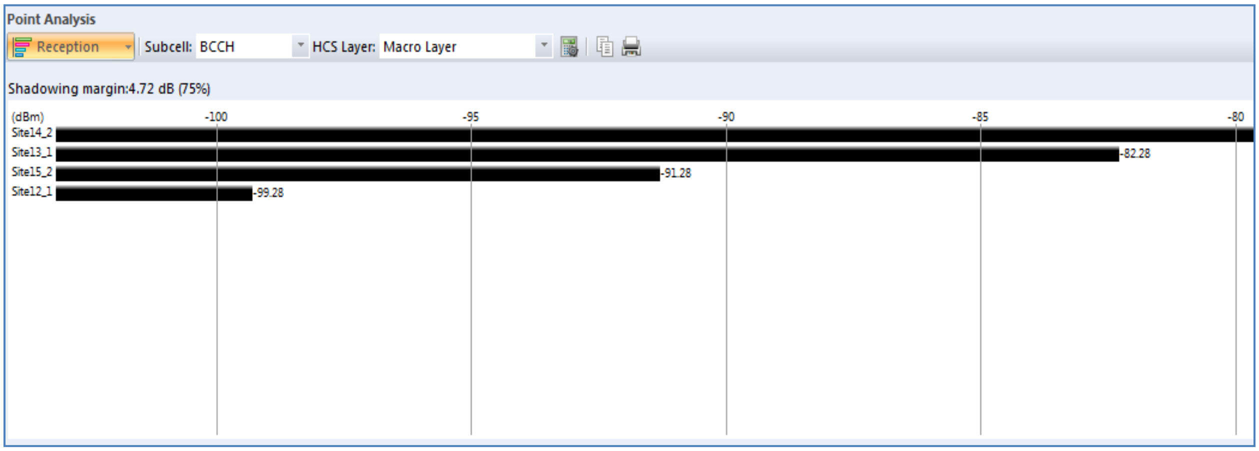
4.3 Performance Analysis of Planned Network

Using point analysis tool of Atoll site 14_2 was chosen from the Awash-Woldia line along with a receiver to analyze the signal reception scenario and other details. The point analysis results appeared as the following shown in Figure4.7 (a)-(c).

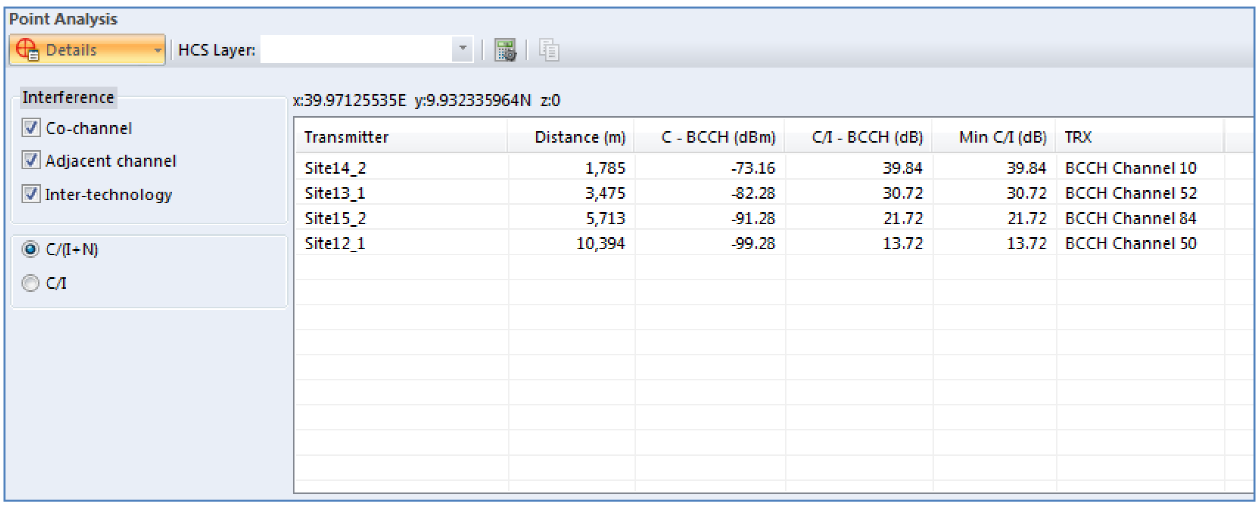
Figure4.7 (a) shows the geographic profile of site 14_2, (b) shows the reception level including the adjacent site whiles (c) provides the result by taking the comparatively better transmitters into account.



(a)



(b)



(c)

Figure4.7: Chosen site for point analysis and performance result

Analyzing the coverage prediction results with respect to calculated values in chapter three, it is quite evident that the planned network provides a satisfactory coverage.

CHAPTER FIVE

5. Conclusions and Recommendations

5.1 Conclusions

The radio network planning of GSMR, like any other cellular technologies, needs extensive assessment in terms of capacity, coverage and quality requirements. The estimations regarding the capacity and coverage should contribute for the deployment and implementation process of the technology by providing substantial data.

On the process of doing this thesis, the only input was the route of the rail line; followed by Google Earth inspection. Real environmental inputs like terrain, traffic, and clutter digital maps would be used. But, it could not be found any of them from any agency for the rail line in consideration. When time comes to have these all digital maps, the result of the planning work will be more efficient and real.

To maintain the future competitive edge of ERC in the world of railway communication, this thesis tries to propose an initiative how to plan the GSMR, the most efficient and standardized communication technology. After all the possible efforts in this thesis work a GSMR system of **48** BTSs with a total of **3.35Mbps** capacity is found to be required for the Awash-Woldia rail line.

5.2 Recommendations.

The work done in this thesis covers the coverage analysis using only the route of the rail line and exporting it to Google Earth in order to inspect the environment and radio access network dimensioning of GSMR network. This work gives a macroscopic dimension and valuable estimation of the GSMR system. Generally great effort has been made in order to make this work complete in all aspects; but some important data is not found. So we can conclude that this work is the early beginning of the complete GSMR planning for the line. When the different digital maps are available, it will be easy to input these digital maps and make the radio plan more real.

And as with all the projects, there is always room for improvements and further enchantments. Same is the case with this thesis work. There are number of ways in which this work can be carried forward. The work done in this thesis covers the access network and interface dimensioning of GSMR network. This can be extended to include core network dimensioning. Using a more accurate traffic maps will yield better results for capacity planning exercise. The techno-economic aspect and cost effective analysis for practical implementation is also a possible extension of this work. In addition this work can be carried forward by including the possibility of passengers to use public networks via the ‘already planned’ GSMR network by switching the public Mobile switching Centers (MSCs) to the GSMR MSC.

Finally, what we need to recommend ERC is that to go through making a real environment digital maps for its rail lines so that accurate GSMR planning will be done in the future.

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