Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Telecommunication Engineering Graduate Program

Cross Boarder Interference on UMTS Mobile Network and Its Impact on Revenue: the Case of Border Town Togowchale.

By

Hagere Demessie

Advisor

Dr. Murad Ridwan

A Thesis submitted to the School of Electrical and Computer Engineering in partial fulfillment of the requirements for the degree of Master of Science in Telecommunication Engineering

November, 2018
Addis Ababa, Ethiopia

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Telecommunication Engineering Graduate Program

Cross Boarder Interference on UMTS Mobile Network and Its Impact on Revenue: the Case of Border Town Togowchale

By: Hagere Demessie

Approval by Board of Examiners

____________________ ________________

Chairman, Dept. Graduate Signature

Committee

Dr. Murad Ridwan ________________

Advisor Signature

____________________ ________________

Internal Examiner Signature

____________________ ________________

Internal Examiner Signature

Abstract

Universal Mobile Telecommunications System (UMTS) which has been standardized by the 3rd Generation partnership project (3GPP) organization, utilizes Wideband Code Division Multiple Access (WCDMA) as radio access technology. UMTS are designed to meet the increasing demands for high data rate applications and greater mobility. High data rate applications include voice, video telephony, Video streaming, File Transfer protocol (FTP), high quality image and wireless internet access. But there are many factors like loading of cell, interference etc. that limits to access these high data rate services or limits the capacity of the systems. The uplink channel is, by nature, an interference-constrained multiple-access channel. Cross border interference is caused due to the usage of the same set frequencies between two adjacent boundaries of different operators. This is the case where other operator locates their base stations in close proximity in order to provide comparable coverage to their customers. This thesis attempts to identify cross boarder interference, analysis to its impacts to the uplink capacity of all service in UMTS systems and loss of revenues is presented. The work starts with UMTS overview and learn some important concept about UMTS uplink channel interference. Then go deep into uplink channel capacity and apply the two load analysis methods to estimate the capacity loss. In the end revenue is calculated using the tariff incurred for each types of service. Ethio telecom can use this research to gain a better understanding of the problem in order to plan a strategy required to be profitable. The results described in this thesis will be a valuable contribution towards the awareness of how interference of another operator's network (which we can' t control) affects the performance of the network elements at boarder town.

Keywords— Cross Boarder Interference, WCDMA, Uplink Channel, Capacity, Revenue

Acknowledgements

I'm very grateful to my Lord Jesus Christ, in whose name and in whose precepts, I try to aim every action in my life.

I want to express my gratitude to my advisor Dr Murad Ridwan. His knowledge, experience and valuable suggestions and corrections gave me the effective support when I couldn't find an answer by myself. Special thanks also to Dr. Dereje Hailemariam and Dr Ephrem Teshale who are also part of my evaluation committee. The constructive feedback and valuable guidance provided by them throughout the project was extremely helpful and encouraging.

I wish to thank also our director at Ethio telecom Engineering Dept., Ato Ashagrie Getnet, his invaluable support. Your help was very important to me, especially at the beginning of my research work when everything was totally new to me. Thank you very much.

I would like to express also my gratitude to Ethio telecom optimization staff as they always gave me support and were always willing to help me whenever I need it and besides, they were cheering me up and encouraging me to make a good work. I hope not to accidentally omit anyone in my list: I want to say many thanks to Ato Alemayehu, Ato Asnake Mokonnen Ato Fisum Merga, Ato Yibeltal, Ato Ahmed and Ato Dawit. It was a great experience and a real pleasure to work with such nice persons and high-level professionals like you.

And last but not least, I want to thank all the support and understanding from my friends and to all my family, specially to my daughter Yididiya Legesse who always encourage me to pursue higher goals and cheer me up in the difficult moments. God bless you all and this work is dedicated to you.

Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

Hagere Demessie ________________

Name Signature

Place: Addis Ababa

Date of Submission: ________________

This thesis has been submitted for examination with my approval as a university advisor.

Dr. Murad Ridwan ______________

Advisor's Name Signature

Table of Content

Contents

List of Figures

List of Tables

List of Acronyms

BS	Base Station
BTS	Base Transceiver Station
CBI	Cross-Border Interference
CDMA	Code Division Multiple Access
CN	Core Network
DFCA	Dynamic Frequency Channel Allocation
DL	Downlink
DT	Drive Test
EM	Electromagnetic
EUL	Enhanced Uplink
EVD	Electronic Voucher Distribution
FDD	Frequency Division Duplex
FTP	File Transfer Protocols
GPRS	General Packet Radio Services
GSM	Global System for Mobile
HSPA	High Speed Packet Access
HSDPA	High Speed Down Link Packet Access

HSUPA	High Speed Up Link Packet Access
ICI	Inter-Cell Interference
ICIC	Inter-Cell-Interference Coordination
ITU	International Telecommunication Union
MS	Mobile Station
OFDM	Orthogonal Frequency Division Multiple Access
PC	Power Control
PIN	Personal Identification Number
QoS	Quality of Service
RF	Radio Frequency
RNC	Radio Network Controller
RNS	Radio Network Sub-systems
RTWP	Receiver Total Wide Band Power
SIM	Subscriber Identity Module
SINR	Signal-To-Noise Ratio
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TEP	Telecom Expansion program

TSL	Time Slots
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile for Telecommunication System
VTU	Virtual Top Up
WARC	World Administrative Radio Conference
WCDMA	Wide band Code Division Multiple Access
3GPP	3rd Generation partnership project

Chapter 1

Introduction

1.1 Background

The cellular industry is a very competitive market. In order to offer best services to their subscribers, service providers need to design and update their networks so that they can provide the best services to the lowest possible cost. Increased frequency spectrum usage for commercial wireless communication, has increased the probability of interference between systems which has to be managed properly for providing the required Quality of Service (QoS) on wireless technologies [1]. Allocation of the same set of frequency bands to two different wireless network operators in adjacent geographical areas can create the problem of co-channel interference.

Today's cellular networks operate on separate frequency bands to avoid interference between them [2]. The operators of these networks obtain an exclusive right to use a given frequency band in their respective country. However, the division based on frequency bands does not apply across national borders. The operators have to resolve their conflicts across the borders themselves. One of the issues is when mobile users of one operator attach to the network of the operator of the other country while still being in their own country.

UMTS networks based on WCDMA have been deployed worldwide as 3rd generation mobile communications system [3]. UMTS provides a clear evolutionary path to High-Speed Packet Access (HSPA). HSPA refers to the combination of High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA). In order to exploit the full potential of WCDMA 5 MHz operation, the performance of HSPA-based radio networks has been further enhanced in terms of spectrum efficiency, peak data rate and latency. HSPA+ as specified in 3GPP Release 7 includes downlink MIMO operation, higher-order modulation (downlink 64QAM, uplink 16QAM) and protocol improvements that specifically allow a high number of "always on" users to be supported in the network. Peak data rates reach 28 Mbit/s in the downlink and 11.5 Mbit/s in the uplink with round-trip times below 50 ms.

In this thesis the interference between two operators (Ethio telecom and Somaliland) networks in the border town Togowchale is studied. The impacts of this interference on UMTS 900 (3G) networks capacity is analyzed and its associated loss in revenue is presented. The calculation and analysis are performed in the uplink schemes.

1.2 Statement of the Problem

The electromagnetic spectrum is a limited resource and is assigned by the respective regulatory authority in each country. Under spectrum management guidelines, regulators have to see that different users and different uses of radio frequency should not interfere with each other. There are many cases in which mobile networks of neighbor countries are assigned the same bands of frequencies. When the signal of neighbor country network is more powerful than that of his own, different implications to the delivery of the service may occur. Particularly, interference problems can disable the possibility of placing calls and generate cases of accidental roaming inside the country [4]. To carryout correction measures in order to reduce / mitigate interference effects to other operators' network in the border areas, cross border coordination between operators is required.

The location of Togowchale in relation to the border with Somaliland is characterized by major commercial activities and constitutes a real market for mobile network operators. Complain has been rise on high demand of market exchange town having around ten different banks, the overshooting and penetration problem causes unreasonable signal coverage inside Ethiopia.

Somali land Network Operators So-Telesom (well known), SOM60 and SOMTEL, having more than 8 sites near the border, dominates Ethio telecom network in and around Togochale town till Aroysa (35KM far from Togochale). This situation enables Somaliland Telecom service providers to operate outside their boundary illegally which results frequency interference in Ethio telecom network and a significant **loss of public revenues**. Therefore, considering these problems this research tries to estimate the loss in revenues based on the analysis of measurement results of a UMTS network.

1.3. Objectives

1.3.1 General Objective

The main objective of this research is to identify cross boarder interference, analyze the impacts on capacity and measure the associated loss on revenues for UMTS mobile network deployed at the border town of Togowchale.

1.3.2 Specific Objectives

This research work has the following specific objectives.

- Study the basic concept of interference on UMTS network uplink capacity analysis process.
- Study the characteristics of cross boarder interference between two mobile operators.
- Carry out case study and identify the problem of interference using optimization tools. The study area has one base stations at border town Togowchale.
- Verify the types and source of interference with Drive Test.
- Measure and evaluate the impacts using data analysis techniques.

1.4. Methodology

The research methodology requires gathering relevant data from specified documents in order to arrive at a more complete understanding of the problem. The use of data recorded by Ethio Telecom's optimization office engineers may reveal the extent of cross border interference and network coverage penetration of the two countries. Further materials from books, reports, scientific journals, websites and valuable resources to be used to get understanding of the cause and impacts of interference. The work starts with preliminary study of UMTS uplink capacity and will apply the following methodologies to accomplish the research in a way it meets the research objectives

- Study area selection and scenarios:
- Data collection:
- Investigate interference problem:
- Verify on drive test result:
- Load analysis based on throughput and RTWP values:
- Measure Loss of Revenue.

1.5. Literature Review

Many documents are concerned with the new UMTS standard and give definitions and descriptions related to UMTS. The book [3], edited by Holma and Toskala, gives a comprehensive introduction to WCDMA, UMTS services and applications, HSPA evolution, Background and Standardization of WCDMA, and Radio Access Network architecture to name just a few.

Muhammad Suryanegara et al. [5] investigated the interference on WCDMA system that caused by CDMA2000 network. Several scenarios and calculation models were applied to measure impacts on uplink and downlink scheme. The results showed that interference from

CDMA2000 influence WCDMA performance significantly. Distance between coexistence terminals Mobile Station and Base Station (MS and BS) , their number, and guard band frequency determined minimum allowed received power at WCDMA BS, which lead to capacity degradation. The distance reduction between WCDMA BS and CDMA2000 MS cause larger capacity loss. For only 10 users of CDMA2000 MS, the 50 m distance made WCDMA capacity loss to be 2.1 %. When number of CDMA2000 MS was increased to be 100 users, capacity loss of WCDMA system also increased to be 20 %. The escalation of CDMA2000 MS (users), would cause bigger loss on WCDMA capacity.

Lukas Klozar et al. [6] presented the results of their measurement on the performance of 3G HSDPA downlink (DL) in terms of Quality of Services (QoS). They point out the relationship between the peak data transmission in DL and uplink (UL), and interferences influencing the DL channel. A rising level of interferences decrease the peak data rate not only in downlink, but also influence transmission in uplink as a consequence of signaling required for retransmitting corrupted data units. Measured results show relation between the performance of an HSPA network and interferences originated from GSM, LTE WCDMA, WiMAX, and also other wireless systems with a channel bandwidth greater than 5 MHz (Wi-Fi, UWB).

S.M et al. [7] presented the impact of noise rises to the uplink capacity and coverage of all-packet-service WCDMA mobile Internet systems in terms of the total throughput per cell in different cell configurations. The impact of external Electromagnetic Interference (EMI) to the pole capacity is also studied. It is shown that the reduction of the pole capacity is caused by the external EMI. Moreover, it can be observed that the impacts of the noise rise to the reduction of the cell coverage is approximately about 14% - 17% in all-packet-service WCDMA cellular systems.

Wen-Tzu Chen and Jyun-Ting Lin [8] developed a method for estimating the impacts of uplink co-channel interference (CCI) on coverage in an IEEE 802.16m system based on the signal-to interference-plus-noise ratio (SINR) requirement. The effects of shadow fading and user random locations are considered for the calculations of average interference power. Their simulation result shows that CCI can cause significant reduction in cell coverage, particularly when mobile users need a large amount of subchannels for high-speed data transmissions.

Lina Lan et al. [9] designed an interference evaluation model by analyzing various factors such as the base station layer, the azimuth ward relationship, and the cell neighborhood relationships. The interference for each frequency is evaluated and the problem frequencies are optimized. This method is verified by a large number of actual datasets from an in-service GSM network. The results show this method has better intelligence, accuracy, timeliness, and visualization than traditional methods.

To summarize what the past related research works have looked at different aspects that contribute to the analysis of the impacts of interference, most of them have focused on UMTS network interference between cells that belongs to one network operators and placing UMTS network parameters in simulations or using analytical models. In this work efforts are made to see the impacts of cross border uplink co-channel interference on a live UMTS networks. This work employs UMTS capacity model to estimate the capacity loss with assumption of a certain number of GSM users as a source of interference and considering their respective distance to base stations. The technique proposed by Holma for load analysis with a measured data are used to map the power level with percentage of load. This scheme achieves to measure the reduction of the capacity due to cross border interference.

1.6. Scope and Limitation of the Thesis

This thesis is aimed to perform analysis on the impacts of interference on the existing UMTS mobile network and the main focus is on uplink capacity analysis considering a case study area at boarder town Togowchale.

The thesis doesn't include the radio-planning stages of Optimization which are out of the scope of it. The analysis performed is limited to UMTS uplink capacity and does not go through technoeconomic analysis, since the term revenue is used only to quantify the capacity loss in more meaningful way.

1.7. Thesis Layout

This thesis consists of six chapters. Chapter 1 consists of an introduction, problem statement, general and specific objectives, literature review and the methodologies used in this thesis. In Chapter 2, the basics of UMTS technology are introduced. The interference, uplink capacity analysis, and the impacts of interference on the uplink capacity are dealt in depth in Chapter 3. Chapter 4 deals with the system design which includes the measurement and analysis set up for the case study area and the procedures followed. While Chapter 5 composes of the results obtained from the simulation and the further analysis based on the results. Finally, Chapter 6 contains the conclusions drawn from the result analysis and some recommendations for future work.

Chapter 2

UMTS Networks System Overview

2.1. Introduction

In this chapter, a basic background for the thesis is provided. Some fundamental principles of UMTS networks are introduced. At first system architecture, introduction to WCDMA followed by its evolution will be described. UMTS networks based on wideband code division multiple access (WCDMA) have been deployed worldwide as 3rd generation mobile communications systems. UMTS provides a clear evolutionary path to high-speed packet access (HSPA). HSPA refers to the combination of high-speed downlink packet access (HSDPA) and high-speed uplink packet access (HSUPA).

Second-generation systems like, for example, Global System for Mobile Communications (GSM) were originally designed for efficient delivery of voice services [3]. Universal Mobile Telecommunication Services (UMTS) networks, on the contrary, are designed from the beginning for flexible delivery of any type of service, where each new service does not require particular network optimization. In addition to the flexibility, WCDMA/High-Speed Packet Access (HSPA) radio solution brings advanced capabilities that enable new services. Such capabilities are

- High bit rates, theoretically up to 2 Mbps in 3rd Generation Partnership Project (3GPP) Release 99, up to 14.4 Mbps in 3GPP Release 5 and up to 28.8 Mbps in Release 7. The practical bit rates are 1–2 Mbps with the first Release 5 deployments.

- Low delays with packet round trip times below 100 ms with Release 5 and even below 50 ms with Release 6.
- Seamless mobility also for packet data applications.
- Quality of Service (QoS) differentiation for high efficiency of service delivery.
- Simultaneous voice and data capability.
- Interworking with existing Global System for Mobile Communications (GSM)/General Packet Radio System (GPRS) networks.

2.2. UMTS System Architecture

This section gives a wide overview of the UMTS architecture. It consists of a number of logical network elements that each has a defined functionality. The network elements are grouped into the Radio Access Network (RAN; UMTS Terrestrial RAN (UTRAN)) that handles all radio-related functionality, and the Core Network (CN), which is responsible for switching and routing calls and data connections to external networks. UTRAN consists of one or more Radio Network Sub-systems (RNSs). An RNS is subnetwork within UTRAN and consists of one RNC and one or more Node Bs. RNCs may be connected to each other via an Iur interface. RNCs and Node Bs are connected with an Iub Interface. In a WCDMA system, the functionality of the Core Network equipment is essentially unchanged from a GSM/GPRS system, but a new interface to UTRAN is required. The Access Network and User Equipment are entirely new.

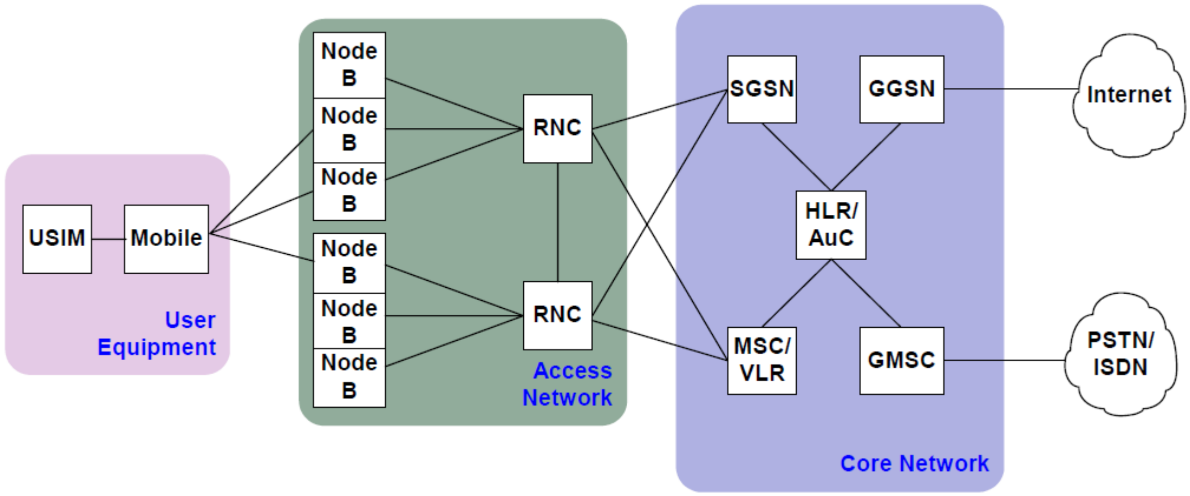

Figure 2.1. UTRAN architecture [3].

- The Mobile Equipment (ME) is the radio terminal used for radio communication over the Uu interface.
- The UMTS Subscriber Identity Module (USIM) is a smartcard that holds the subscriber identity, performs authentication algorithms, and stores authentication and encryption keys and some subscription information that is needed at the terminal.
- The Node B converts the data flow between the Iub and Uu interfaces. It also participates in radio resource management.
- The Radio Network Controller (RNC) owns and controls the radio resources in its domain (the Node Bs connected to it). The RNC is the service access point for all services that UTRAN provides the CN, e.g. management of connections to the UE.
- Home Location Register (HLR) is a database located in the user's home system that stores the master copy of the user's service profile.

- Mobile Services Switching Centre/Visitor Location Register (MSC/VLR) is the switch (MSC) and database (VLR) that serves the UE in its current location for Circuit-Switched (CS) services. The MSC function is used to switch the CS transactions, and the VLR function holds a copy of the visiting user's service profile, as well as more precise information on the UE's location within the serving system.
- Serving General Packet Radio Service (GPRS) Support Node (SGSN) functionality is similar to that of MSC/VLR but is typically used for Packet-Switched (PS) services. The part of the network that is accessed via the SGSN is often referred to as the PS domain.

2.3. WCDMA System Overview

This section describes the characteristics of the WCDMA system in general. For a more detailed description, see [3]. WCDMA is a wideband Direct-Sequence Code Division Multiple Access (DS-CDMA) system, i.e. user information bits are spread over a wide bandwidth by multiplying the user data with quasi-random bits (called chips) derived from CDMA spreading codes. In order to support very high bit rates (up to 2Mbps), the use of a variable spreading factor and multi code connections is supported. The chip rate of 3.84Mcps leads to a carrier bandwidth of approximately 5 MHz DSCDMA systems with a bandwidth of about 1MHz, such as IS-95, are commonly referred to as narrowband CDMA systems. The inherently wide carrier bandwidth of WCDMA supports high user data rates and also has certain performance benefits, such as increased multipath diversity. Subject to his operating license, the network operator can deploy multiple 5MHz carriers to increase capacity, possibly in the form of hierarchical cell layers.

2.4. Multiple Access Methods

Multiple access methods in cellular networks concern the way multiple users can effectively share the system resource so that each of them can obtain certain quality of service. Therefore, multiple access and interference management are coupled with each other [12].

FDMA

Frequency Division Multiple Access is a multiple access method in which users are assigned specific frequency bands. The user has the sole right of using the frequency band for the entire call duration. First generation analog systems (e.g., AMPS) use FDMA

TDMA

Time Division Multiple Access assigns a frequency band to a set of users. Each user is allowed to transmit in predetermined time slots. Channelization of users in the same band is achieved through separation in time.

CDMA

Code Division Multiple Access is a method in which multiple users occupy the same time and frequency allocations and are channelized by unique assigned codes. The signals are separated at the receiver by using a correlator that accepts only signal energy from the assigned code channel. All other signals in that frequency band contribute only to the noise. Both CDMA2000 and WCDMA use the same fundamental concepts of CDMA modulation.

OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a wideband modulation scheme designed for high data rate networks, whose original link level design is based on a single user scenario. However, when combined with multiple access schemes, it bears some unique properties compared with conventional systems. As introduced above, when operated at high data rate, the performances of TDMA, FDMA or CDMA could be significantly degraded under severe multipath environments, advocating the implementation of prohibitively complicated equalizers, which are usually not acceptable in most practical systems especially at the MS. In OFDM, a wideband signal is simultaneously transmitted on multiple orthogonal (non-interfering) narrowband subcarriers, each of which experiences a near-°at fading channel.

Therefore, no equalizer is required. Compared with conventional FDMA, in which a large frequency separation between carriers is required for avoiding the cross-talks, OFDM achieves the same goal with consecutive frequency spectrum usage, thus is more efficient.

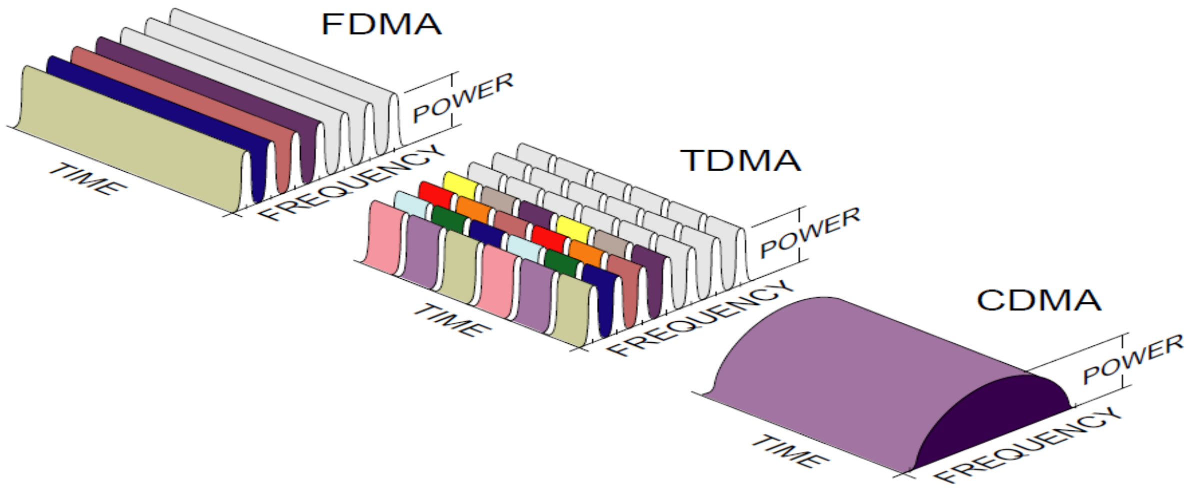

Figure 2.2: Multiple Access Methods

2.5. WCDMA Evolution

WCDMA evolved from GSM/GPRS, inheriting much of the upper layer functionality directly from those systems. The first commercial deployments of WCDMA were based on a version of the standards called Release 99. Enhanced Data rates for GSM Evolution (EDGE) is another system in the GSM/GPRS family that some operators have deployed as an intermediate step before deploying WCDMA. HSDPA was introduced in WCDMA Release 5 to offer higher speed Downlink data services. Release 6 introduces the Enhanced Uplink (EUL) that will provide faster data services for the Uplink. In order to exploit the full potential of WCDMA 5 MHz operation, the performance of HSPA-based radio networks has been further enhanced in terms of spectrum efficiency, peak data rate and latency. HSPA+ as specified in 3GPP Release

7 includes downlink MIMO operation, higher-order modulation (downlink 64QAM, uplink 16QAM) and protocol improvements that specifically allow a high number of "always on" users to be supported in the network. Peak data rates reach 28 Mbit/s in the downlink and 11.5 Mbit/s in the uplink with round-trip times below 50 ms.

3GPP Release 8 specifies further improvements for HSPA+ such as downlink dual carrier operation and the combination of MIMO and 64QAM modulation. Both features enable a maximum data rate of 42.2 Mbit/s in the downlink. Furthermore, circuit-switched voice over HSPA provides optimized support of voice services in an HSPA packet-switched radio access network. In addition, latency is further improved by allocating common E-DCH, 3GPP has been also working to specify a radio system called Long-Term Evolution (LTE), where the target for finalizing 3GPP standardization is during 2007. Release-7 and -8 solutions for HSPA evolution would be worked in parallel with LTE development, and some aspects of LTE work are also reflected on HSPA evolution.

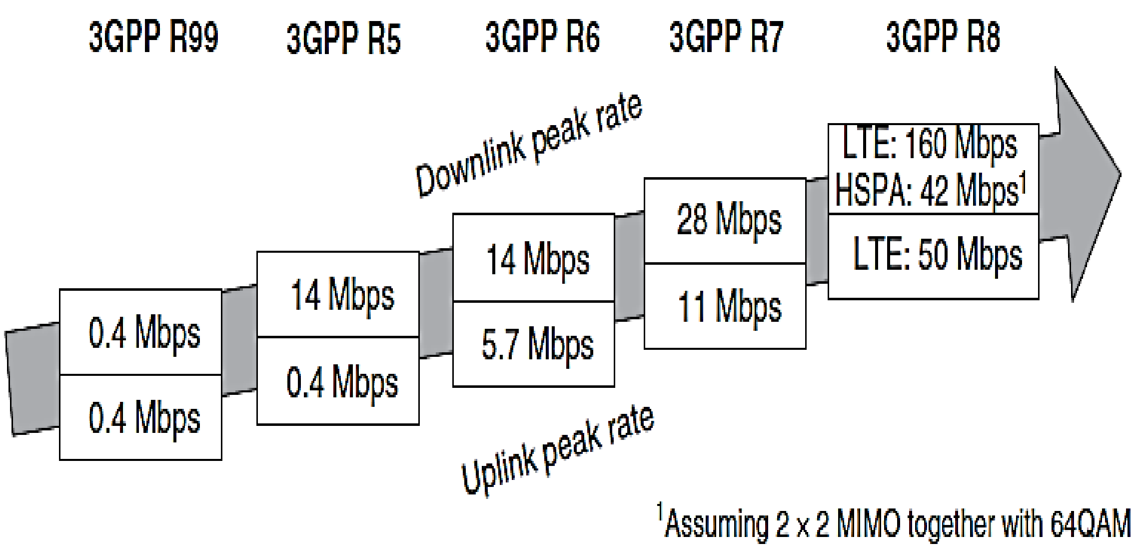

Figure 2.3. Peak data rate evolution for WCDMA [3]

2.6. Economics and Pricing Policies in 3G Mobile

In order to understand how mobile phone networks, generate revenue and what significant impact the interference plays in the generation of revenue, it is necessary to understand the network services and tariff incurred for each service. Charging and pricing are essential issues for network operations of 3G mobile networks. A primary target of differentiated pricing of Internet services is the prevention of system overload and an optimal resource usage according to different daytimes and different traffic intensities [20]. Among the proposed pricing proposals, flat-rate pricing [21] is the most common mode of payment today for bandwidth services. Flat-rate pricing is popular because of its minimal accounting overhead. A flat-rate encourages usage but does not offer any motivation for users to adjust their demand. Dynamic pricing models that take the state of the network into account in the price determination have been proposed as being more responsive. Usage-based pricing regulates usage by imposing a fee based on the amount of data actually sent, whereas congestion-sensitive pricing uses a fee based on the current state of congestion in the network. According to current Ethio telecom pricing policy, a hybrid pricing policy combining the notion of flat-rate and a usage-based pricing is considered for the revenue analysis.

2.6.1. Revenue

All mobile phone network operators have at least two mode of payment through which revenue is generated. The first is the value channel where the service is granted, before payment is expected for the service, namely the post-paid value channel. Traffic is generated on the mobile phone network and bills are typically settled afterwards at month end or whenever the contractual agreement entered into with the client stipulates that he is obliged to do so. The second, and according to reports by far the most popular, is the pre-paid value channel [18]. Emerging markets, especially in Africa, lack proper financial control mechanisms [19]. A sales channel through which the client purchases a product, before it is consumed is therefore, beneficial in monetary terms, but also in the value associated with the limited liability (or diminished credit risk) on the part of the mobile phone network. Typically, a client purchases a fixed amount of airtime and then would eventually load that airtime onto his handset for use at some future point in time. This use of airtime is referred to as consumption or usage of airtime.

2.6.2. Network products

A mobile phone network, like most companies in the service industry, is reliant on selling their services to maintain an existence. A mobile phone network maintains a great amount of cellular network infrastructure used in the realization of its service. The cellular network infrastructure collectively forms a wireless network that spans the network coverage area. The wireless network uses electromagnetic waves to transmit data between mobile handsets. Data that can be wirelessly transmitted between handsets is the product that mobile phone networks sell to their clients. The data product (also called airtime) offered by the mobile phone networks is referred to as the amount of time a person consumes while working on a mobile handset. The following airtime bearing products exist in a typical mobile phone network.

A) Physical vouchers

Physical vouchers are tangible cards or pieces of paper containing a Personal Identification Number (PIN). The PIN can be dispensed in exchange for a representative amount of airtime. Ethio telecom presented nine different denomination voucher card/air time to its prepaid service customers, which extended from minimum of birr 5 to maximum of birr 1000. I.e. birr 5, birr 10, birr 15, birr 25, birr 50, birr 100, birr 250, birr 500 and birr 1000 voucher card/air time.

Figure 2.4: voucher card/air time to prepaid service customers

B) Virtual Top Up (VTU)

VTU is a term used for airtime that is purchased for a nominal value in any specified denomination. The denomination is exchanged for a corresponding amount of airtime that is loaded directly onto a client's account.

C) Subscriber Identity Module (SIM) cards

A SIM card is an identity module that is inserted into a mobile handset. The SIM card identifies a client on the network. SIM cards normally have airtime loaded on them and the airtime becomes active on the client's account when the card is activated by the client (normally when the card is inserted into a mobile handset and the handset containing the SIM card is switched on for the first time).

2.6.3. Network systems

This section shows the software and hardware systems and human-driven operation processes that interact with the flow of revenue within a mobile phone networks pre-paid value channel. A brief description of the functionality provided by each system which impacts on revenue within the pre-paid value channel is given according to the illustration of these systems in Figures 2.5

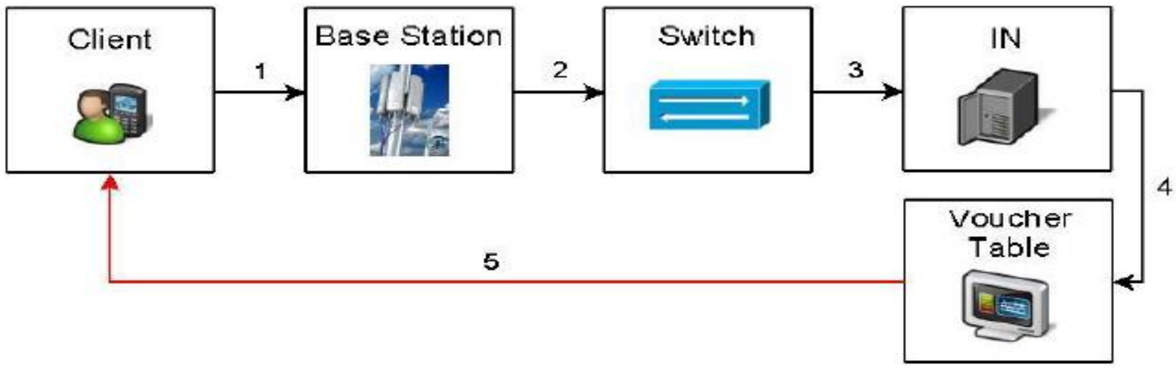

Figure 2.5: The high-level architecture of the systems interacting with a mobile phone network's credit applied transaction

Step 1: The client sends a request via the existing mobile phone infrastructure to recharge his account with a specified amount of airtime. The client interacts through any available protocol for communication with a mobile phone network's Base Transceiver Station (BTS).

Step 2: The BTS passes the request through to the switch. The switch handles all network traffic and decides what to do with any specific network request.

Step 3: The switch passes the request on to the mobile phone network's Intelligent Network (IN). The IN handles all data related to a network's pre-paid clients.

Step 4: The IN verifies the necessary airtime bearing product (a physical voucher or EVD) in the voucher table. If the airtime bearing product is not a physical voucher or EVD (therefore a VTU or SIM card), the IN would still verify the transaction for validity using a different system, however, similar to the voucher table in nature.

Step 5: If the verification step is successful the client would now have the airtime available for usage on his account. The IN is updated with this information and the client is notified.

Chapter 3

UMTS Uplink Capacity

3.1. Introduction

The uplink of WCDMA was significantly enhanced in 3GPP Release 6 with the introduction of the enhanced uplink feature also referred to as HSUPA (High Speed Uplink Packet Access). In particular, the feature introduced the capability to schedule packet data transmissions on the uplink in a spectrally efficient manner. The key attribute of the enhanced uplink feature was the Hybrid automatic repeat request (H-ARQ) method that introduces time diversity in fading channel environments which in turn improves spectral efficiency as well as facilitates delay critical applications by targeting early packet terminations. The introduction of a 2ms transmission time interval (TTI) allows for a very short latency

3.2. Interference in WCDMA

Interference is an important factor that limits the capacity of WCDMA systems. The interference in a WCDMA cell can be from the same cell, from the neighboring cell that is. (during handoffs and can be due to thermal noise) of the cell. The air interface capacity of a CDMA cell is not pre-determined from the available spectrum amount and thus it cannot be planned very accurately. That is, the capacity is dependent on the performance of the receivers in a time varying environment and also on the interference within its own network and the spectrally adjacent network. The capacity might also be limited by the maximum available number of spreading codes and hardware resources. One of the most challenging parts of radio network planning is the estimation of the required traffic since the radio network planner has to know, at least approximately, what kind of services are going to be used, the likely user locations and hot-spot areas. It is also crucial to know the degree of asymmetry in multimedia services. In web-browsing, for example, the downlink traffic is larger than the uplink traffic and this has to be considered during network planning as well.

In most cases the WCDMA network is interference limited and thus the radio network planning can be considered as being the control of the interference throughout the system. When the number of users (or user bit-rates) increases the interference increases, meanwhile the required MS and BS transmission powers have to increase, in order to achieve a required performance. The change of the cell range due to change of the load of the cell is usually referred as "cell breathing". When the load of the cell and therefore the interference increases, the coverage threshold increases as well, shrinking the coverage area. In order to achieve the required coverage area for a given service level, the coverage areas have to be planned assuming maximum loading of the system in order to avoid coverage holes due to the cell breathing effect. Thus, in the coverage planning phase, the possible load (number of users or used throughput) has to be considered. For both uplink and downlink the interference present at the receivers also varies in time. Some interference sources can be nearly invariant in time whereas other sources may be very "peaky". This includes strong short-term variations of the received signal. These large fluctuations happen especially with higher bit-rates and with packet transmissions where the transmitter sends short packets by using relatively high power. For instance, the data transported via TCP/IP throughout the internet consists of packets and tends to be very bursty. Hence, this internet related data traffic also causes interference peaks in the radio network.

The WCDMA uplink channel is, by nature, an interference-constrained multiple-access channel. All active users simultaneously transmit asynchronously over the same bandwidth, and each user's signal is interfering with other users' signal. The interference, at the NodeB receiver antenna input is composed of three components namely, intra-cell interference, inter-cell interference and thermal noise. The intra-cell interference component represents the sum of the WCDMA uplink waveforms of all the users who communicate with the NodeB cell. This also includes the self-interference caused by the multi-path channel on each user's transmitted waveform. In general, these waveforms are non-orthogonal to each other due to the fact that the users' transmissions are offset with respect to each other and the fact that a non-zero cross-correlation exists between each user's scrambling code. Hence, the process of descrambling and de-spreading a particular user's waveform with its own scrambling code and channelization code respectively (also referred to as a matched filter) is not enough to fully eliminate the other users' energy or the self-interference caused due to the multipath channel. Generally, the interference sources can be grouped as follows:

- Inter symbol interference (ISI). This interference is due to overlapping symbols in the same bit-stream caused by multipath radio propagation.
- Own cell interference caused by other users connected to the same cell.
- Other cell interference caused by users connected to other cells in the same system.
- Power leakage from the adjacent carrier in the same system. This includes intra operator interference and inter operator interference. Intra operator interference is usually rather small since the interference sources are controllable.
- Interference from other systems (such as GSM, WCDMA TDD, CDMA2000, etc.)
- Interference from other, non-controllable sources such as traffic, illegal transmissions, radar systems, electronic devices, etc.

All these interference types decrease the system performance (coverage and capacity) and have to be minimized if possible, in order to increase the spectral efficiency of the network.

3.3. Factor Affecting WCDMA System Capacity

There are many factors that increase or decrease the capacity of WCDMA systems. Some of them are loading of cell, interference factor, voice activity factor, configuration of antenna, type of coding scheme used, Interference cancellation techniques etc. Two of the above-mentioned factors that affect the capacity of WCDMA system is discussed as below.

A) Loading of cell

In cellular system, a single cell is surrounded by many cells and due to handoff's strategies, a particular cell is said to be loaded by users from other cell using the particular cell and producing loading effect. This loading effect decreases the performance of a particular cell or we can say that capacity of cell decreases and this effect is measured by loading factor.

B) Interference

Interference is an important factor that limits the capacity of WCDMA systems. The interference in a WCDMA cell can be from the same cell, from the neighboring cell i.e. during handoffs and can be due to thermal noise of the cell.

3.4. Spectrum Reframing

To deal with spectrum scarcity, some countries have changed legislation so that other services can use portions of the spectrum initially allocated to a different service/technology. This is called reframing: repurposing a frequency that was initially allocated to one technology for another one. For example, an operator may have a license to operate on the 900 MHz spectrum for GSM. To better deploy UMTS or LTE, the operator could potentially free some of the GSM capacity and allocate it to LTE or UMTS.

3.5. Benefits of Refarming

Refarming is a cost-effective way to increase capacity for UMTS/LTE without the need to bid for new spectrum. Refarming is not limited to GSM, since UMTS spectrum can also be refarmed to increase LTE capacity. Another interesting benefit for operators is that lower frequencies (usually allocated to GSM networks) provide much better coverage. Lower frequencies reach farther and have less penetration loss than higher frequencies, enabling better rural coverage and improved indoor urban coverage. Higher frequencies typically deliver greater capacity, rather than coverage, in urban areas. As an example of better coverage, UMTS900 can increase areas served per Node-B between 44% (in urban areas) and 119% (rural areas) when compared with UMTS2100. This difference in performance lets operators economically provide 3G applications over much greater areas. In terms of cost, the lower propagation loss at 900 MHz means fewer base stations. Compared to networks using the 2100 MHz core-band 3G spectrum, costs can be 50 to 70% less. Operators can provide less densely populated areas with 3G services more cost-effectively. QoS is enhanced because fewer base stations means fewer handovers. Considering that the vast majority of phone calls are initiated indoors, the higher in-building penetration afforded by lower-frequency bands is a significant factor

The challenges of Refarming include avoiding disruption to existing users on the band/technology that will be refarmed and encouraging them to migrate to new services. The operator needs to maintain GSM quality as the process takes place, not compromising customer satisfaction and experience. Avoiding service degradation means understanding traffic patterns and managing how traffic will be served. Spectrum may be interleaved between operators, requiring reconfiguration to avoid fragmentation. This can require considerable coordination and cooperation. After reconfiguration, a full site/cluster audit needs to be carried out to understand new coverage, traffic distribution, and interference/quality

3.6. UMTS 900 Deployment Scenarios

The deployment of UMTS in the 900 MHz bands does not mean the immediate replacement of GSM networks by UMTS. Some operators may plan to deploy only UMTS in 900 MHz band. For some others (and it is believed for most of the existing GSM operators) the most probable transition strategy is to use part of the 900 MHz frequency band for deploying UMTS in order to offer 3G services, while keeping GSM networks in operation. GSM and UMTS will be in co-existence and operated in adjacent channels. Particularly, the deployment of UMTS in the

900 MHz band in rural areas allows providing 3G services at a much lower cost compared to the deployment of UMTS in 2100 MHz band. UMTS 900 combines the benefits of WCDMA with better propagation advantage at lower carrier frequency. UMTS900 offers CAPEX gains (a smaller number of NodeBs) in rural morphologies and better in building penetration in urban morphologies compared to UMTS2100. UMTS900 and GSM900 are expected to co-exist in Band VIII. The deployments can be in coordinated or uncoordinated mode. Coordinated operation requires one-to-one overlay of UMTS900 NodeBs with GSM900 BTSs. The locations of two technologies' sites are non-collocated in uncoordinated operation. [14] recommend conservative carrier to carrier separation: 2.6 MHz for coordinated operation, 2.8 MHz for uncoordinated operation. In order to avoid or minimize the interference between two operators, it is suggested for the operator who plans to deploy UMTS and GSM in the same band that it is better to use the so called "Sandwich" frequency arrangement as shown below.

The inter-cell interference component represents the sum of the WCDMA waveforms of all the users who do not communicate with the NodeB cell under consideration. The Node-B is not aware of these users and hence does not power control or rate control of these users. Such interference among users fundamentally limits the maximal data throughput of an uplink cellular system, as well as the maximal number of co-existing users.

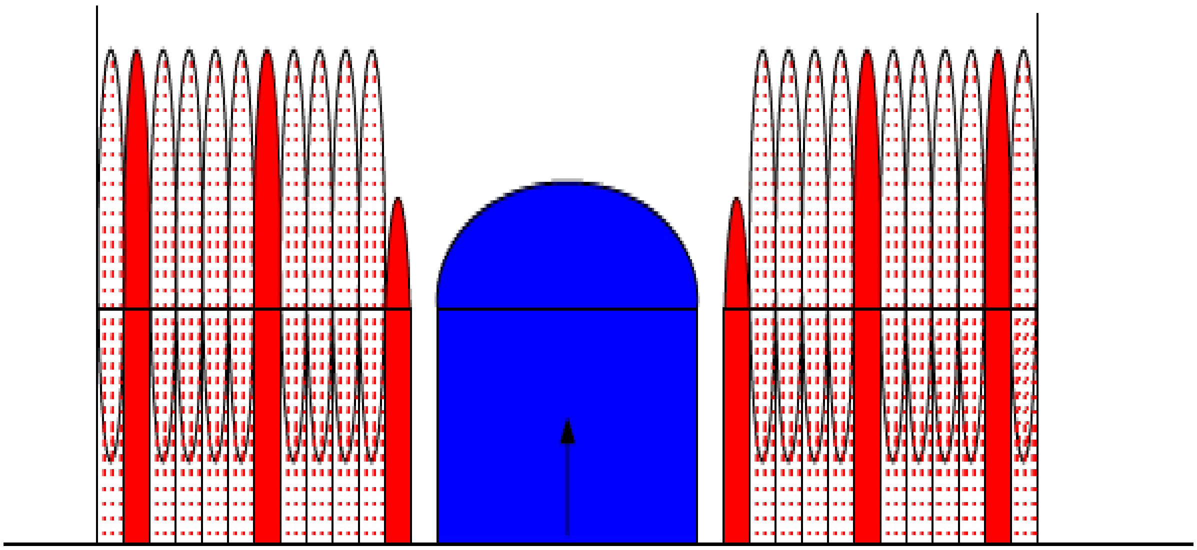

Figure 3.1: Suggested frequency arrangement for an operator deploying one UMTS carrier

3.7. WCDMA Frequency Variants

The WCDMA deployment has started in Europe and Asia in the mainstream 2.1 GHz band I with a total 2 60MHz allocation. The WCDMA terminals typically include WCDMA2100 together with a number of GSM bands. WCDMA deployment at 900 MHz band VIII starts during 2007 and requires, in practice, dual-band 900 þ 2100 terminals. The WCDMA networks in the USA started at 1.9 GHz band II and expanded to 850 MHz band V. The WCDMA terminals in the USA need, in practice, to have dual-band WCDMA 1900 þ 850 MHz supported. There are also multiband terminals available supporting the 850, 1900 and 2100 bands. The new 3G band in the USA at 1.7/2.1 GHz is band IV and called Advanced Wireless Services (AWS). The WCDMA deployments have started at the AWS band. Altogether, WCDMA is currently deployed in three different frequency bands in the USA.

Table 1: WCDMA frequency bands in 3GPP (3)

Operating Band	3Gpp Name	Total Spectrum	Uplink (MHz)	Downlink (MHz)
Band I (Main stream WCDMA Band)	2100	2 X 60 MHz	1920 – 1980	2110 - 2170
Band II (PCS Band in Americas)	1900	2 X 60 MHz	1850 – 1910	1930 - 1990
Band III (Europe, Asia and Brazil)	1800	2 X 75 MHz	1710 – 1785	1805 -1880
Band IV (New 3G band in USA)	1700 / 2100	2 X 45 MHz	1710 – 1755	2110 – 2155
Band V (USA and Asia)	850	2 X 25 MHz	824 – 849	869 - 894
Band VI (Japan)	800	2 X 10 MHz	830 – 840	875 - 885
Band VII (New 3G band)	2600	2 X 70 MHz	2500 – 2570	2620 - 2690
Band VIII (Europe and Asia)	900	2 X 35 MHz	880 -915	925 - 960
Band IX (Japan)	1700	2 X 35 MHz	1750 – 1785	1845 - 1880
Band X (Extended band IV)	1700 / 2100	2 X 60 MHz	1710 – 1770	2110 - 2170

Chapter 4

Modelling and Analysis

This chapter describes the chosen study area scenario and introduces the cross-border interference problem in a border town deployment of UMTS network. The focus is to analyze the impact of inter-cell interference on uplink capacity and measure the loss. In order to study this issue, a live UMTS networks between two different operators in the border town Togowchale is considered allowing for detailed analysis by measurement, analytical methods and simulation capturing the main UMTS system characteristics.

General Setup and Assumption

A live deployed UMTS networks of site ID 151421 with three cells of U111 configuration is considered. Perfect power and admission control operation is assumed.

Power Control

Tight and fast power control is perhaps the most important aspect in WCDMA, in particular on the uplink. Without it, a single overpowered mobile could block a whole cell.

Admission Control

Admission control algorithms, in general, decide whether a new connection could be admitted without impacting the QoS of current connections in a network. In addition, AC algorithms must be designed to fulfill a grade of service (GoS), i.e., call blocking rate.

The existence of AC algorithms in mobile phone systems protects the cellular network and users while achieving network performance objectives.

Cell-Specific Measurement

Two cell specific performance measurement are performed.

1) Cell mean RTWP values
2) Cell throughput: is based on the calculation of a percentile level of the UE throughput distribution in a cell

4.1. Study Area Selection (Background Information)

The study area (Togowchale border) is host to Somali people, (Ethiopians and Somali land). Geographically located at the border point of the eastern part of Ethiopia to the Somaliland. Administratively it is under Jijiga zone of the Somali Regional State. Because of its importance to the general economic development of the country and the high ambition of Ethiopian government to use Berbera port of Somaliland [10], the Ethiopian government constructs a first grade 700KMs asphalt road from Addis Ababa to Togochale and established all it's necessary and supportive public institutions including.

- Commercial Bank of Ethiopia.
- Ethiopian Customs Authority.
- Ethio Telecom
- Ethiopian Electric Power Corporation.
- Ethiopian Immigration Authority and others.

In addition to that many other private enterprises established in Togochale town including, Wogagen, Awash and NIB international Banks. All these public and private institutions are functioning and doing their desired goals. The main characteristic of this border town is high market area for different commodity including contraband goods that comes from another world through Somaliland. The people perform various marketing functions such as exchange and transportation. Most of the transaction is done on cash basis with Ethiopian money as a preferred method of payment. Telecommunication services plays such a vital role in their daily existence. Ethio telecom has two sites which swapped and the newly constructed during Telecom expansion project (TEP). As investigation report done by optimization team has shown that mobile network penetration occurred on both sides crossing the border creates substantial and vital impacts on the two countries.

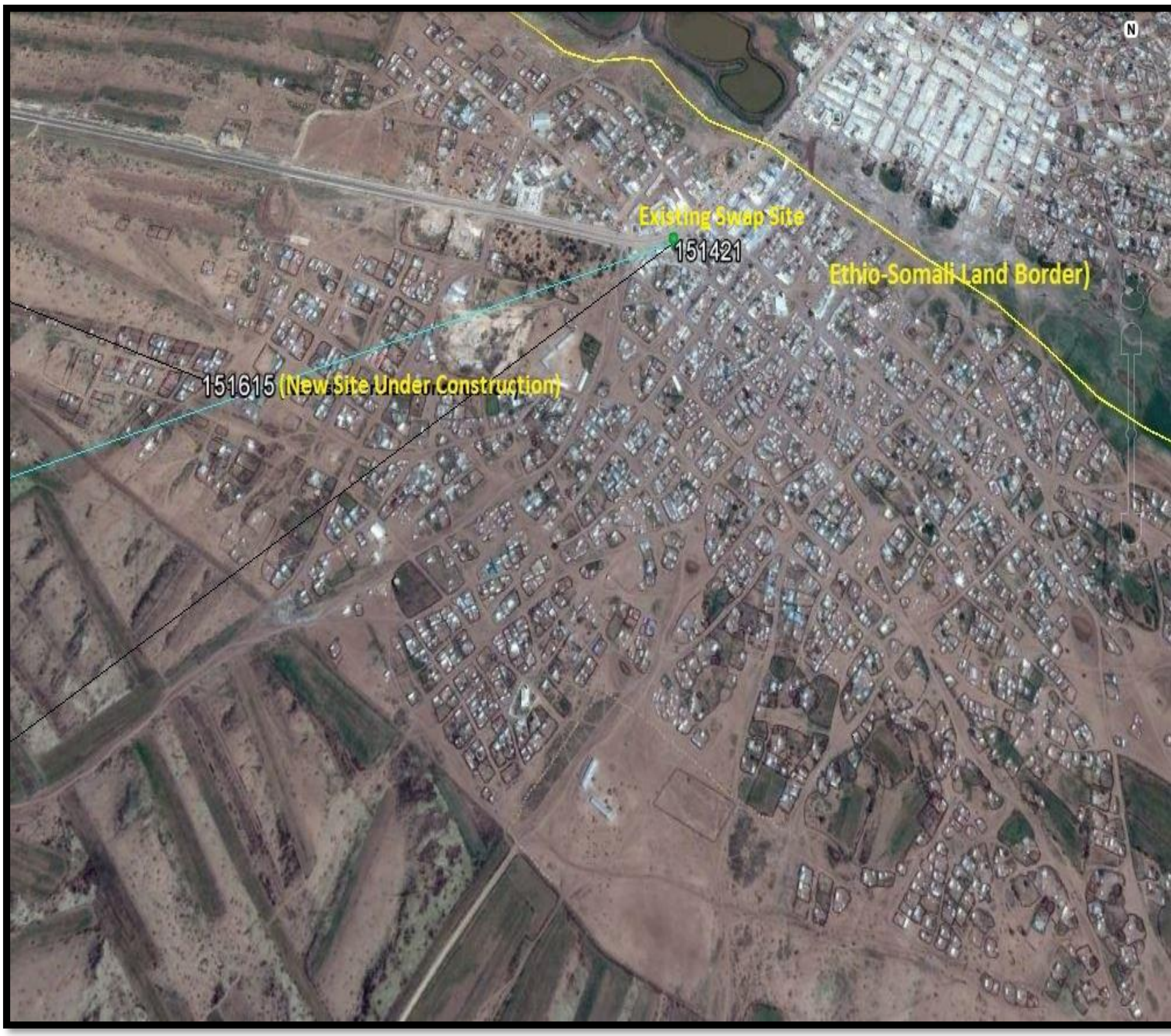

Figure 4.1: DT Area Digital Map Overview [11].

4.2. Investigation of Interference Problem

The best method for finding uplink interferences is observing the average RTWP among network operation indexes. To confirm interference and determine its strength a one-month (31 days) times 24 hours data is collected. Normally the unloaded network RTWP is about –105.5 dBm. If the average RTWP of some cells reaches about –95 dBm, 10 dB higher than that of unloaded network, the cells encounter uplink interferences. If the average RTWP of some cells reaches about –85 dBm, 20 dB higher than that of unloaded network, the cells encounter strong uplink interferences

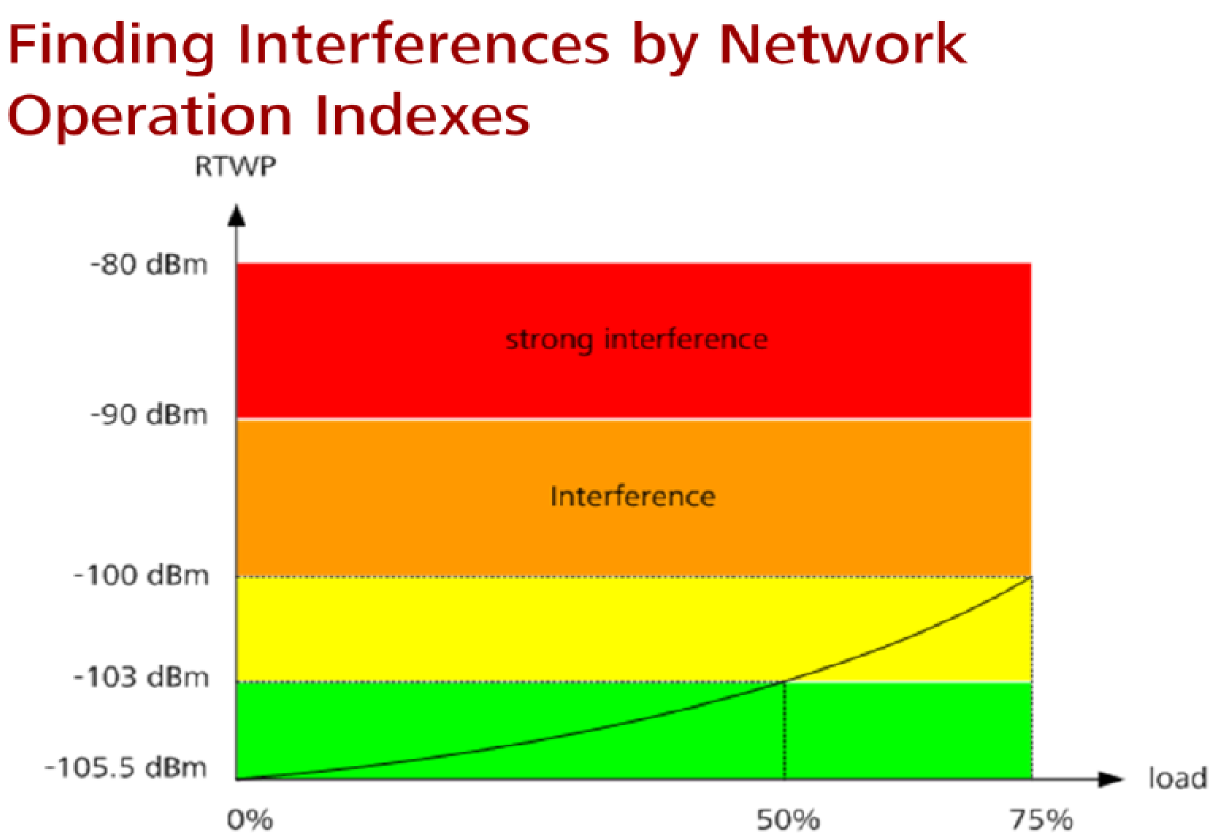

Figure 4.2: Uplink interference and RTWP values

4.3. Verification of Interference with Drive Test

Drive Test is a test performed in cellular network regardless of technology (GSM, CDMA, UMTS, LTE etc.…) usually performed in order to analyze and optimize the network quality. The interference problem which was identified by analysis of KPI can be verified by drive test results. The drive test allows a deeper analysis in the field identifying area of each sector of coverage, interference, evaluation of network change and various other parameter.

Drive Test Types**:**

The main drive test types are: Performance Analysis, Integration of new sites and change parameter of existing sites.

Radio Parameter

CPICH EcNo: Chip energy by noise, common pilot channel EcNo is the ratio of the energy of the chip and the combined of all the signal including the specific pilot channel. It also shows the level of noise disrupting the specific CPICH.

Ranges for EcNo

0 to -7 Good

-7 to -10 Acceptable

-10 to -35 Bad

CPICH RSCP: Received signal code power is the level of the signal received by the UE or in simple RSCP is the total power of the entire cell or a specific common pilot channel received by user Equipment

Ranges of RSCP:

-30 to -75 Good

-75 to -85 Acceptable

-85 to -140 Bad

Tx power: is the transmitting power of the mobile station. Its value can vary. The minimum the Tx power of the mobile station the beer it is for call quality

RSSI: received signal strength indicator is the total power of the entire common pilot channel received by the mobile station including neighbor's interference and noise

RSSI = RSCP + EcNo

RSSI Range

0 to -75 Good

-75 to -85 Acceptable

-85 to -140 Bad

SIR: Signal to interference ratio is the ratio of energy in the DPCCH (dedicated physical control channel) to that of the interference and noise received by the user equipment.

Target SIR: it is the target signal and interference ratio the mobile equipment is supposed to achieve by increasing or decreasing its power. It is usually set by the use power control procedure.

4.4. System Model

This section describes a system model and approaches to evaluate uplink capacity reduction due to inter cell interference coming from another operator. In the first part calculation is going to be performed in one cell scenario where 1 (one) WCDMA Base Station (BS) – refer to 3G Node B - serving numbers of WCDMA Mobile Station (MS). This cell was affected by user of GSM BS and number of GSM MS as co channel interferer. The work was using parameters summarized in Table 1. In the second part of the assignment a more "realistic" scenario (scenario based on real data) is analyzed. The purpose is to analyze the uplink load and two methods are used.

Uplink Co-channel Interference

The scenario when uplink co-channel interference is caused from neighboring cell is presented in figure 4.3, mobile user (m) served by Somaliland network. As it was verified with drive test the two operators use the same frequency channel. In this situation, the uplink of Ethio telecom UMTS will suffer with the interference coming from GSM user of Somaliland networks.

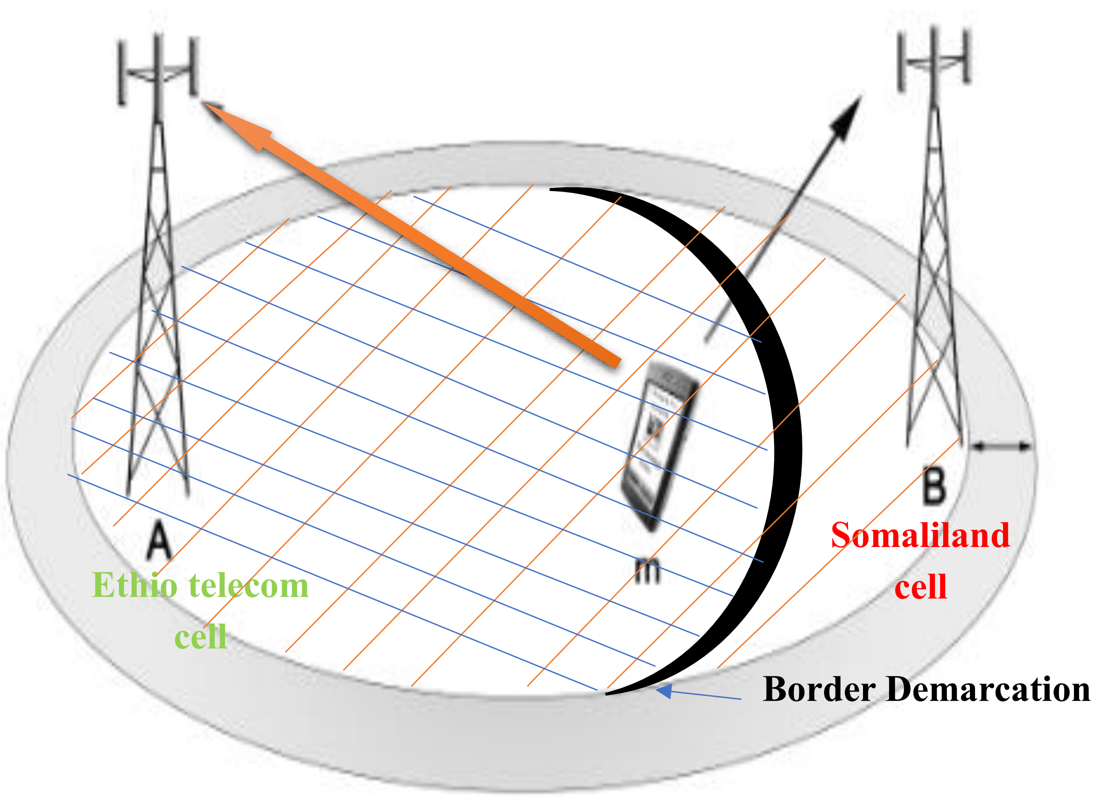

Figure 4.3: Inter-cell interference on cell A from users (m) while served by cell B

Table 2: Parameters for Uplink Capacity Calculation

	Value	Description
M		Uplink call numbers practically supported in one cell of single carrier;
G_p	10 log (3840/bit rate)	Processing gain; G_p =W/R
η	50%	Cell load factor
Eb/No target (ρ)		Demodulated SNR
V	0.6	Service activation factor
f_{Ul}	0.81	Other-to-own-cell interference ratio
N	-103.2 (dBm)	Thermal Noise or Receiver Noise Power

4.4.1. WCDMA Capacity Model

The capacity of WCDMA system is an important parameter in Universal Mobile Telecommunication System Networks. The capacity of WCDMA system is basically determined by signal to noise ratio or mostly said E_b/N_o (Bit energy to effective noise power spectral density) and by the processing gain of the system. The processing gain is defined as the ratio of the spreading bandwidth of the system to the data bit rate for the selected application i.e. voice, data & multimedia etc. With this assumption the processing gain includes the effect of channel coding as well. The criteria for the received power for MS i can be written as [15]:

$$\frac{\left(\frac{W}{R_i}\right) P_i}{I_{own} + I_{other} + N} \geq \rho_i \quad (1)$$

where pi is the received power from the mobile i at the base station reception. The required Eb/N0 for the mobile i and for a certain service quality is ρi, I_{own} is the interference coming from the mobile user's own cell, I_{other} is the interference coming from other adjacent cells, and N is the thermal noise. By defining the other-to-own cell interference ratio as *fuL= I other/I own*, by writing *I own* as a sum of the received signal power from the mobile's own cell the equation becomes

$$\frac{\left(\frac{W}{R_i}\right) P_i}{\sum_{\substack{j=1 \\ j \neq i}}^{k} P_j v_j \cdot (1 + f_{ul}) + N} \geq \rho_i, \quad (2)$$

where ν*j* is the average voice activity factor indicating the portion of time when the user is actively transmitting and k is the number of users in the cell. When every user has the same service (constant *R*,ν and ρ) the received power can be written as:

$$P = \frac{N\rho}{\left(\frac{W}{R}\right) - v.\rho.(k-1).(1+ful)} \quad (3)$$

The own cell interference is the total power received from the own cell users. This equation gives the minimum allowed received power at the BS from MS as a function of the number of users in a cell in order to obtain a satisfactory link performance for a certain service. The theoretical maximum capacity (pole capacity) of the system can be calculated by setting the denominator of the Equation (3) to zero:

$$k = \frac{\left(\frac{W}{R}\right)}{\rho \cdot v \cdot (1 + f_{ul})} + 1 \tag{4}$$

The total interference in UL is the sum of the own and other cell interferences + thermal noise *N*. If we use the previous formula for the own cell interference and f_{UL} as the other-to-own cell interference ratio in uplink we get:

$$i = I_{own} + I_{other} \tag{5}$$

$$i = \frac{N \frac{R\rho(k-1)(1+f_{UL})}{w}}{1 - \frac{R\rho(k-1)(1+f_{UL})}{w}} \tag{6}$$

where η_{UL} is defined as the loading of the system. Therefore, the total system interference at the BS is:

$$i + N = \frac{N\eta_{ul}}{1 - \eta_{ul}} + N = \frac{N}{1 - \eta_{ul}} \tag{7}$$

The typical maximum loading value of the network is around 0.6, which gives about a 4dB reduction in the link budget. The capacity of the system in uplink can be defined as the maximum number of users for which the loading value is lower than a certain maximum value. The UL loading of the system, which is equivalently defined as:

$$\eta_{ul} = \frac{R\rho\,(k-1)(1+f_{ul})}{W}, \tag{8}$$

is thus dependent on the number of users, user bit-rate, target Eb/N0 value (ρ), other-to-own cell interference ratio (f_{ul}) and the used chip rate. From these variables ρ and f_{ul}) are dependent on the propagation environment, i.e. mobile speed, radio channel conditions (multipath), radio network topology etc. The target Eb/N0 is dependent on the particular service and the mobile speed but it is also dependent on the characteristics of the radio channel and the power control. It is also dependent on whether the mobile is in SHO or not. In the case of SHO the Eb/N0 is lower due to additional diversity in reception [16], [17]

Calculation

There are two calculations in uplink scheme, measured by varying distance, and number of GSM MS. It was designed by setting GSM MS as source of interferer. The first calculation aimed to get minimum allowed received power at WCDMA BS, while the second one provide its capacity degradation.

1) Calculation of the minimum allowed received power at WCDMA BS
   - Calculating the minimum allowed received power at WCDMA BS before the presence of interference from GSM MS, by substituting parameters into (3).

- Calculating the interference power from 1 (one) GSM MS by using (10). The ACIR value is appropriate to the guard band used in calculation. ACIR value for 5 MHz guard band is 32.7 dB

$$P_{Rx1} = P_{Tx1} - \text{ACIR} - \text{PathLoss (dBm)} \quad (9)$$

The propagation model used in calculation was Free Space Loss with 3G 900MHz uplink center frequency carrier (fc) 897. 5 MHz. The pathloss was measured by using (11). We set distance between WCDMA BS and GSM MS to be 500 m and 1000 m.

$$FSPL(dB) = 20\log(d) + 20\log(f) + 32{,}44 \quad (10)$$

Where: d is the distance of the receiver from the transmitter (km), f is the signal frequency (MHz)

- Calculating the total interference power from GSM MS. The interference power from every GSM MS was assumed to be equal so the total interference power can be derived from (11).

$$\text{I GSM (Watt)} = \text{Number of GSM MS x } P_{RX1} \quad (11)$$

- Number of GSM MS to be 10, 50, 100, 150 and 200
- Calculating the minimum allowed received power at WCDMA BS after the presence of the GSM MS by judging I GSM , as shown in (12).

$$P\ min\ after = \frac{(N+I_{GSM})^{*}\rho}{\left(\frac{W}{R}\right) - v*\rho*(k-1)*(1+f_{UL})} \quad (12)$$

2) Calculation of the Capacity Loss: The steps to measure capacity loss are the following.

- Calculating WCDMA capacity (kint) when WCDMA BS has been interfered by GSM MS. In order to attain specific trend, we only varied distance factor from 50 to 500 m and number of GSM to be 10 and 200 MS. The results were obtained by using (14)

$$k_{int} = 1 + \left[\frac{\left(\frac{W}{R}\right) - \frac{(N+I_{GsM})^{*}\rho}{P_{min\ bef_0re}}}{v*\rho*(1+f_{UL})}\right] \quad (13)$$

Calculating the percentage of capacity loss by using (14).

$$\%\ Capacity\ Loss = \left(1 - \frac{k_{int}}{k}\right) * 100 \quad (14)$$

4.4.2. Uplink Load Analysis

To measure uplink load two methods are used: load estimation based on wide band received power, and load estimation based on throughput [3].

A) Load Estimation Based on Wideband Received Power

The wideband received power level can be used in estimating the uplink load. The received power levels can be measured in the Node B. Based on these measurements, the uplink load factor can be obtained. The calculations are shown below. The received wideband interference power, I total, can be divided into the powers of own cell (intra-cell) users, I own, other-cell (inter-cell) users, I other and background and receiver noise, PN:

$$I_{total} = I_{own} + I_{other} + PN \quad (15)$$

Uplink Load Factor

The noise rise (NR) is defined as the ratio of total wideband power to the thermal noise power Po received at base station.

$$NR = \frac{P_{total}}{P_0} = \frac{P_0 + P_{other} + P_{own}}{P_o} \quad (16)$$

This equation can be rearranged to give the uplink load factor η_{UL}

$$\eta_{UL} = \frac{1}{1 - NR} \quad (17)$$

where $\mathbf{I}_{\mathbf{total}}$ can be measured by the Node B and PN is known beforehand. The uplink load factor $\boldsymbol{\eta}_{\mathbf{uL}}$ is normally used as the uplink load indicator. For example, if the uplink load is said to be 60 % of the WCDMA pole capacity, this means that the load factor η_{UL}= 0.6

The WCDMA bandwidth is 5 MHz, so the related background noise is -106 dBm. Based on this relationship, the mapping between RTWP and the load can be determined, as shown in Figure 4.5

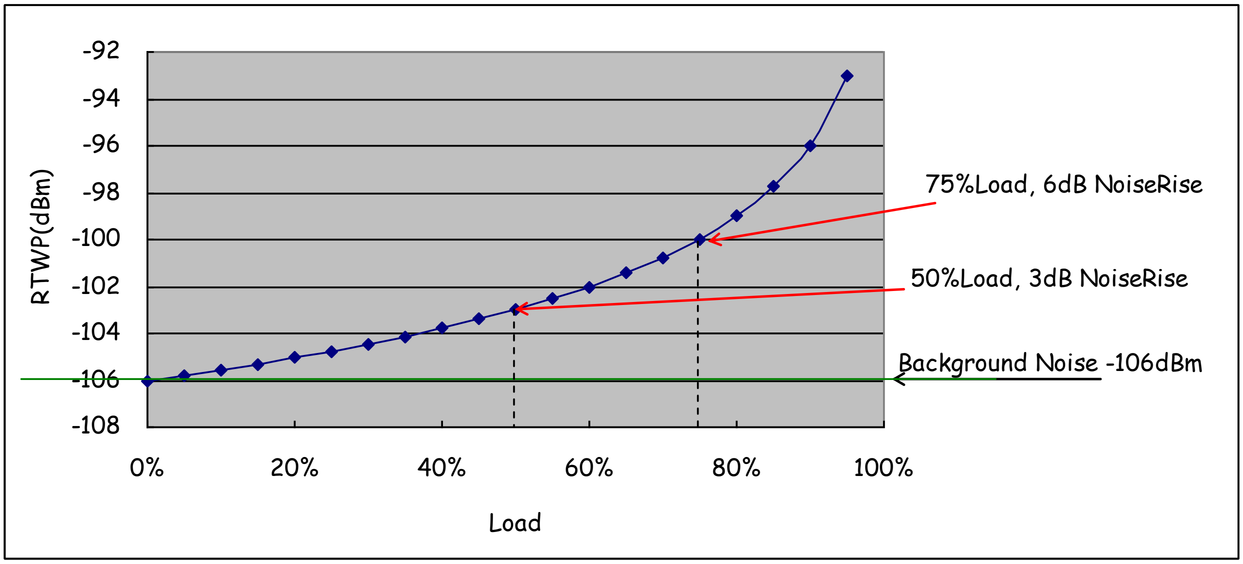

Figure 4.4: Uplink Load, RTWP values and Noise Rise

For the considered Network, the system target load (maximum load considered normal) is 75%. The corresponding normal RTWP value should be below -100 dBm. The corresponding equivalent user number (EUN) ratio should be lower than 75% If the RTWP measurement of a cell is always above -100 dBm, the cell is considered as overloaded. When the uplink is overloaded or if the RTWP is too high, the cell coverage will shrink, the call quality will be degraded, and new calls will be blocked

B) Load Estimation Based on Throughput

The uplink load η_{UL} factor can be calculated as the sum of the load factors of the UEs that are connected to this Node B [3}:

$$\eta_{\mathrm{UL}} = (1+i) \cdot \sum_{j=1}^{N} L_j = (1+i) \cdot \sum_{j=1}^{N} \frac{1}{1 + \frac{W}{(E_b/N_0)_j \cdot R_j \cdot \upsilon_j}}$$

where N is the number of UEs in the own cell, W is the chip rate, Lj is the load factor of the jth UE, Rj is the bit rate of the jth UE, (Eb=N0) j is Eb=N0 of the jth UE, vj is the voice activity factor of the jth UE, and i is the other-to-own cell interference ratio.

Table 3: 3G 900 MHz - UL Link Budget

HSUPA

Scenario		**Scenario Dense Urban site U2100**	**Scenario sub Urban site U900**
Environment		Dense Urban	Sub Urban
Penetration Type		Deep Indoor	Indoor day light
Target HSUPA Throughput	kbps	256	64
UE category		Cat8 PA3 LMMSE TTI2 Rx2	Cat8 PA3 LMMSE TTI2 Rx2

User Equipment			
UE Output power	dBm	**23**	**23**
Antenna gain	dBi	**0**	**0**
Device Position (Body loss)	dB	4	4
EIRP	dBm	**19**	**19**
NodeB			
Antenna Gain	dBi	**18**	**18**
Feeder loss	dB	**0.5**	**0.5**

Thermal noise	dBm/Hz	-174	-174
NodeB Noise Figure	dB	3	3
Noise bandwidth	Hz	3840000	3840000
SINR	dB	-14.8	-20.2
NodeB sensitivity	dBm	-119.8	-125.2
Margins & Gains			
Penetration margin	dB	21	7
Coverage Probability	%	95%	95%
Shadowing standard deviation	dB	9.2	8.1
UL Shadowing margin	dB	5.2	5.2
RoT Max (Rise over Thermal)	dB	3	3
MHA Gain	dB	0	0
Soft Handover Margin (SHO)	dB	2	2
Outputs			
UL Max Allowable Path Loss (MAPL)	dB	125.2	144.5
Propagation Model		COST-231 HATA	COST-231 HATA
NodeB Antenna Height	m	30	40
UE Antenna Height	m	1.5	1.5
UL frequency	MHz	1980	915

DL frequency	MHz	**2170**	**960**
A(hm) UL	dB	0.05	0.02
A(hm) DL	dB	0.05	0.02
Kc	dB	**3**	**-4**
K1 (including Kc and A(hm)) UL	dB	140.6	120.5
K1 (including Kc and A(hm)) DL	dB	141.9	121.2
Delta K1 UL/DL	dB	1.3	0.7
K2		35.2	34.4
UL Cell Edge	Km	**0.36**	**4.97**
Site area	Km^2	0.3	48.1
RSCP Threshold for ASSET for HSUPA Target Throughput			
CPICH Power	dBm	**33**	**33**
RSCP Threshold for RNP tool	dBm	**-76.0**	**-94.7**
DL Pathloss at Cell edge	dB	126.5	145.2
Average HSDPA Cell throughput	Mbps		**3.12**

Chapter 5

Results and Discussion

The purpose of this chapter is to present the analysis of the calculation, measured and simulation results in a scenario described in chapter 4 and according to system model already mentioned in that chapter.

5.1. Drive Test Result

- Figure 5.1 shows the absolute Radio frequency channel number (ARFCN) of GSM is given to UMTS 900
- Verification through drive test, the presence and source of interference (interference checkup) result shows that
  - Cross border GSM frequency interference on our UMTS 900 network
  - The absolute Radio frequency channel number (ARFCN) of GSM with respect to Receiver signal level (RSL).
  - The recorded RSL can be said significant, compared to the threshold value -85 dBm
- GSM 900 absolute radio channel number 62-86 is given to UMTS 900 sandwiched between two groups. In such deployment scenario frequency scanning of GSM channel results shows that most of the UMTS absolute radio frequency channel number scanned with a significant receiving signal level. Frequency scanning test verify that there is a source of GSM 900 uplink interference on UMTS 900 network.

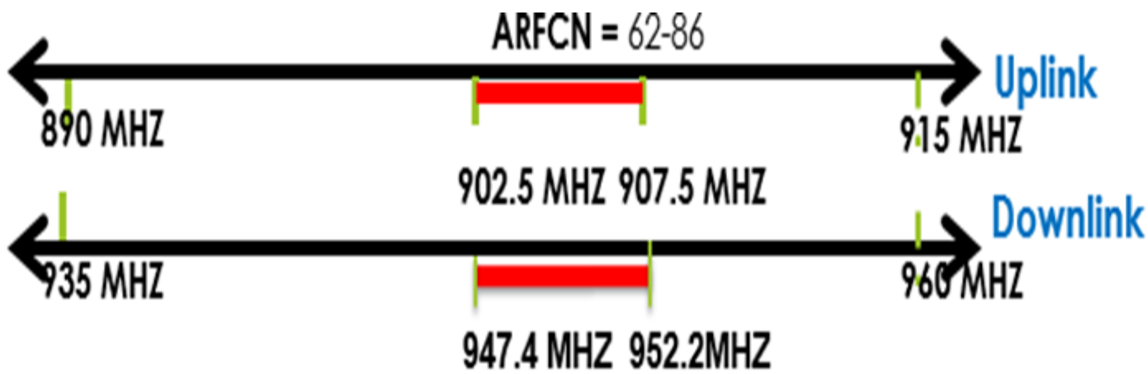

Figure 5.1: UMTS assigned channel in GSM 900 MHz band

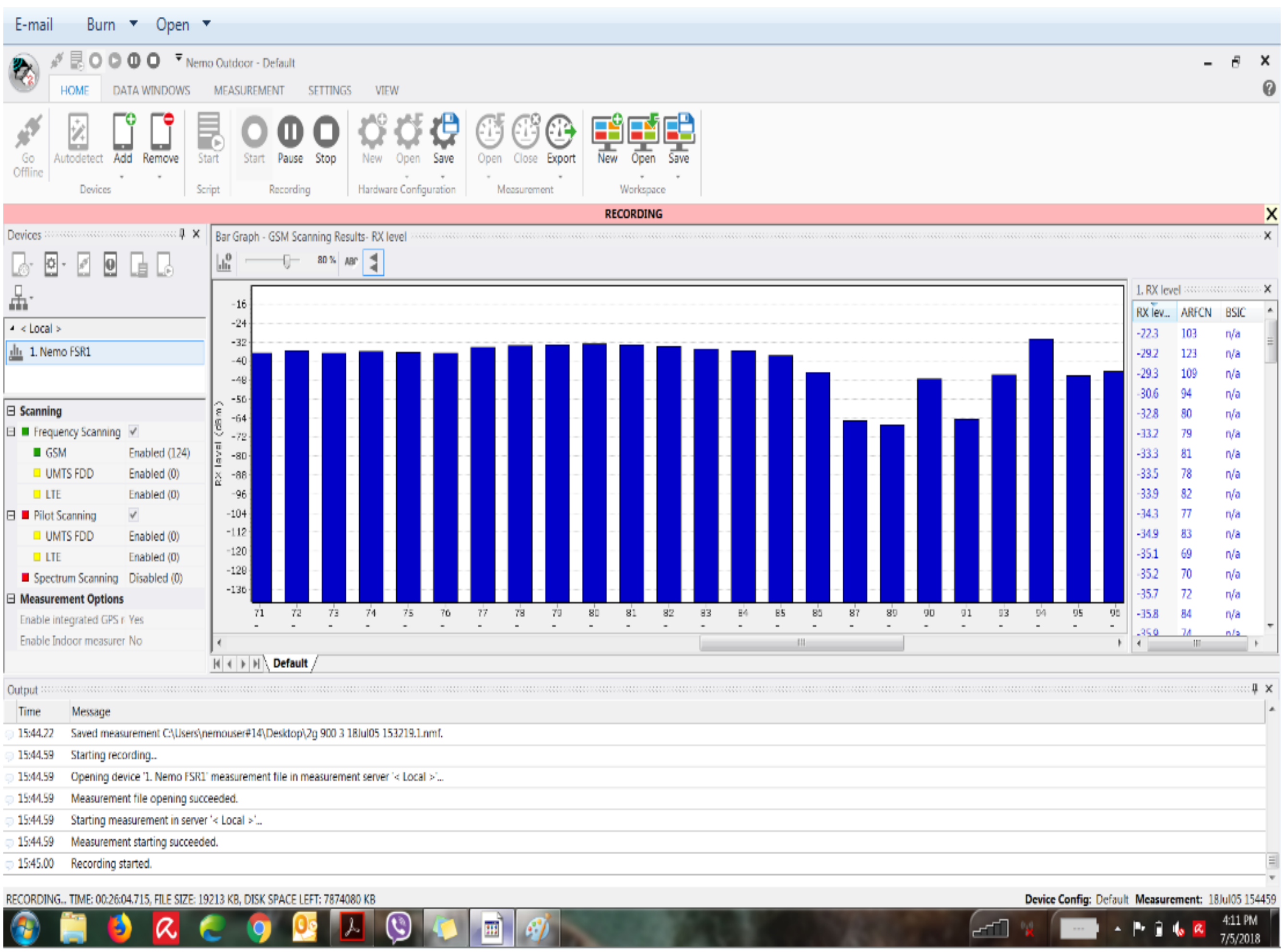

Figure 5.2: Drive test result using Frequency Scanner[11].

5.2. Uplink capacity Analysis

By applying WCDMA capacity model outlined in section 4.4.1 the capacity with 50% cell load and parameter values was calculated as shown on Table 4

Table 4: WCDMA UL Capacity for 50 % cell loading of Single service

WCDMA single cell capacity					
	CS12.2 Voice	**CS64**	**PS64**	**PS128**	**PS384**
Bit Rate (kbps)	12	64	64	64	64
G_p (Processor gain)	314.75	60	60	30	10
E_b/N_0 (demodulated SNR)	2.630	1.862	1.445	1.288	1.148
system Loading (%) η	0.5	0.5	0.5	0.5	0.5
V (Service activation factor)	0.67	1	1	1	1
f_{Ul} (other-to-own cell interference ratio)	0.81	0.81	0.81	0.81	0.81
Gp / (E/No) required)	119.666	32.221	41.509	23.287	8.709
1/ (1+0.65) *0.67	0.825	0.552	0.552	0.552	0.552
K=one single cell capacity for separate service (CH) (supplied capacity/cell)	**50**	**9**	**12**	**7**	**3**

Table 4 summarized that for a given spreading bandwidth of 5 MHz i.e. 3.84 Mps chip rate, as the data rate increases, the number of users in a cell decreases for a given bit energy to noise ratio. For a target E_b/N_o there are 50 users of 12.2kbps data rate, 12 users of 64kbps data rate, 7 users using the cell having 128 kbps data rate and only approximately 3 users accessing the WCDMA networks with data rate of 384 kbps. So as the bit energy of a particular service increases, the number of user decreases.

5.3. Uplink Calculations

A. Calculation of the minimum allowed received power at WCDMA BS (with and without Interference)

The calculations generated graphs showing the minimum allowed received power at WCDMA BS for different number of users. The value before and after the presence of interference from GSM MS, could be compared by observing the graphs, at the distance of 1000m (1 Km)

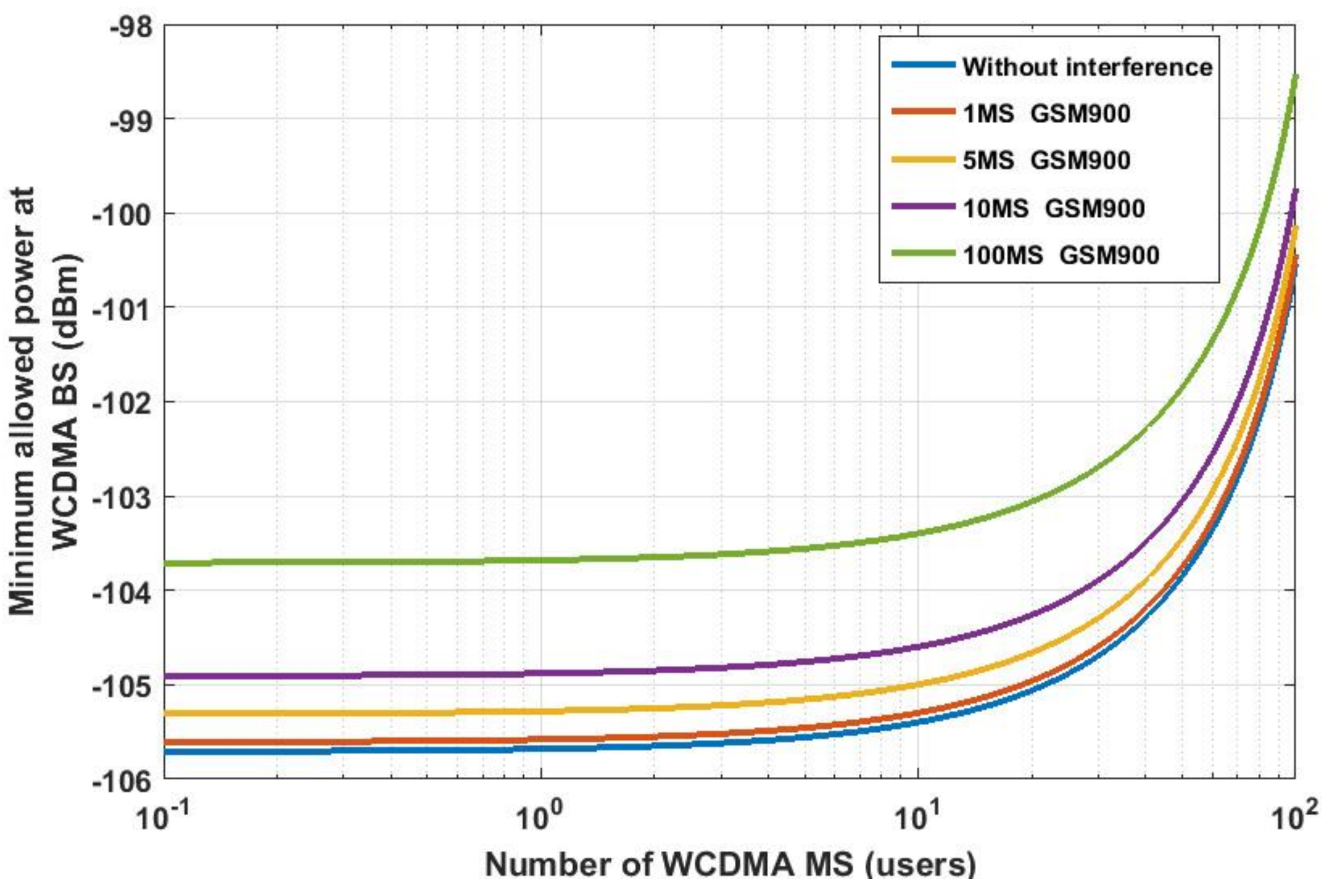

Figure 5.3: Minimum allowed received power at WCDMA BS for certain number of WCDMA users (distance between WCDMA BS and GSM MS is about 1000 m)

Figure 5.3: shows calculation results when distance between WCDMA BS and GSM MS was 1000m by using guard band 5 MHz The lines figure minimum allowed received power when there were 1, 5, 10, and 100 GSM MS

The minimum allowed received power at WCDMA BS can be referred as the coverage threshold [15]. It reflects number of users which can be served in uplink scheme. Results imply interference from GSM MS increase minimum allowed received power at WCDMA BS, then decrease number of served user. We may also see that quantity of GSM MS plays significant role. The greater number of GSM MS, cause the addition of minimum allowed received power at WCDMA BS.

B. Calculation of the Capacity Loss

Result of Capacity Loss calculation is showed in Fig.5.4 The distance reduction between WCDMA BS and GSM MS may cause larger capacity loss. For only 10 users of GSM MS, the 100 m distance made WCDMA capacity loss to be 0.2 %.

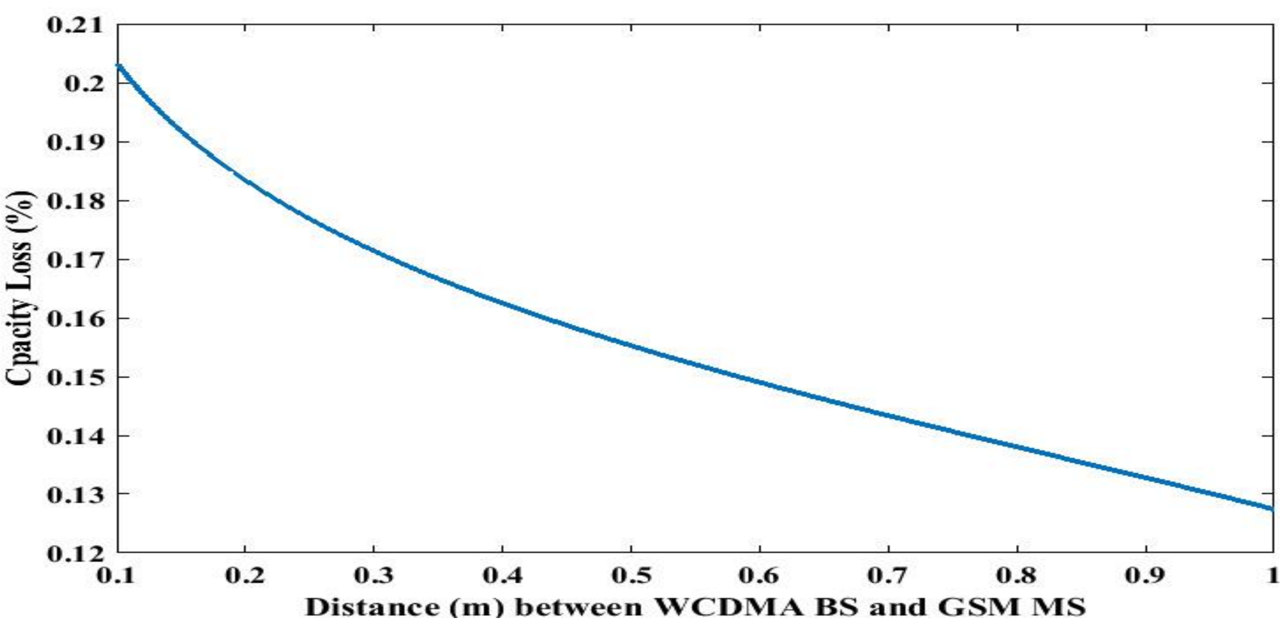

Figure 5. 4: Uplink Capacity Loss (GSM MS is 10 users)

5.3. Uplink Load Analysis

The purpose of this section was to determine the load using the measured data making the analysis for each one of the services.

5.3.1 Load estimation based on RTWP values

Figure 5.5 shows the graph generated from OSS data using MATLAB. For this case, it was also proposed in the KPIs definition to measure the RTWP and see if its level exceeds the target. Observing the average RTWP of one-month (31 days and 24 hours) OSS data, the values indicate that RTWP of the three cell much exceeds the optimum level. Using the approach presented in [Holma] which was described in section 4.5, a maximum Noise Rise (in dB and UL Load in terms of the uplink load factor can be estimated. For almost half of the observation time (duration of the collected data), the RTWP values is greater than --100 dBm which means 6 dBm noise and this are equivalent to 75 % of cell Load. The worst-case scenario with strong external interference level was also observed. The average RTWP value of the three cell is the RTWP value of the site and equal to – 100dBm.

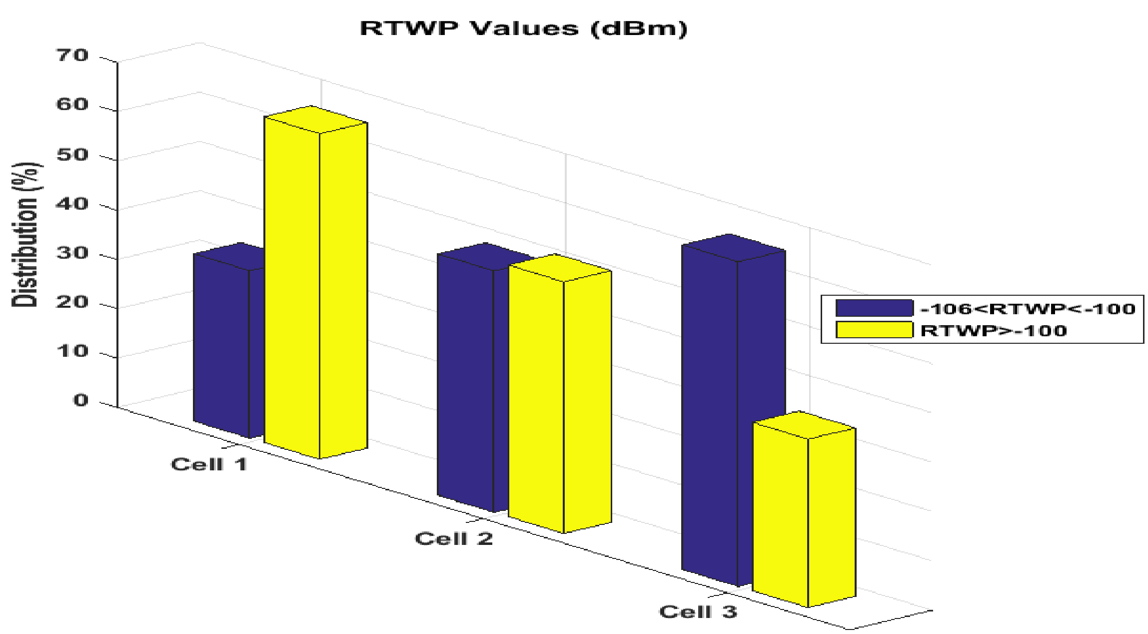

Figure 5.5: RTWP values of the three cells

5.3.2 Load estimation based on throughput

As it can be seen in Figure 5.6 and 5.7, even for a BH traffic, the obtained throughput and voice traffic were still far from the target level

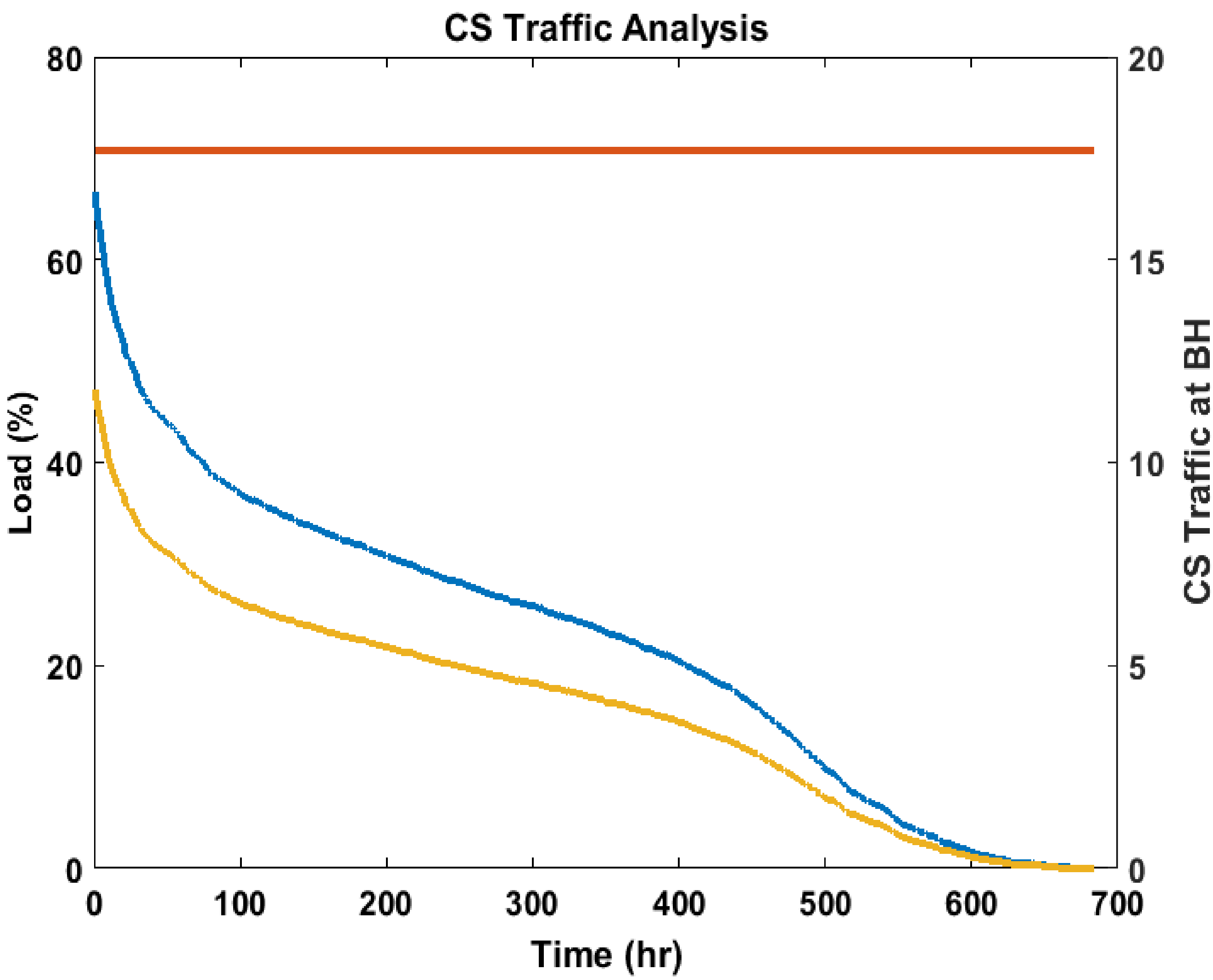

Figure 5.6: Offered and carried Busy hour CS traffic.

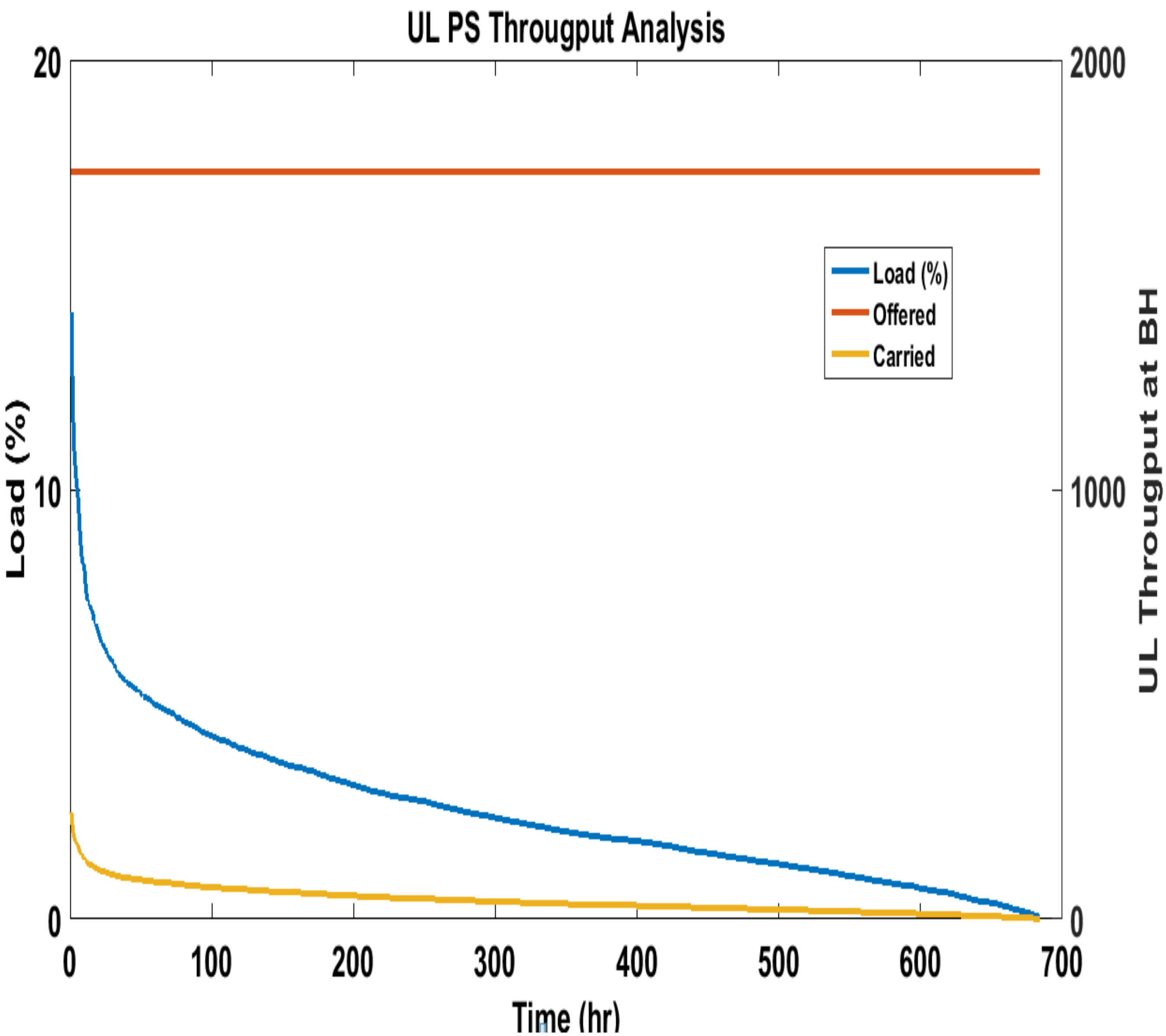

Figure 5.7: Offered and carried BH uplink PS throughputs

Table 5: Cell capacity estimation prosses during planning and dimensioning phase

<table>
<tr><td colspan="12" align="center">Requirement Analysis

Total average traffic per sub requirement (Kbps) =
2.00 *1024*1024*8/30 x3600 x 0.08 = 12.43</td></tr>
<tr><td colspan="3">Monthly traffic (PS+CS) allowance or Requirement from marketing (GB/M/U)</td><td colspan="3">Total average traffic per sub requirement (Kbps)</td><td colspan="3">Uplink Average Traffic per sub requirement (kbps)</td><td colspan="3">Uplink Average Traffic per sub requirement (MB/BH/Sub)</td></tr>
<tr><td colspan="3" align="center">2.00</td><td colspan="3" align="center">12.43</td><td colspan="3" align="center">2.92</td><td colspan="3" align="center">1.28</td></tr>
<tr><td colspan="12"> Cell capacity estimation (Throughput) Uplink Average Traffic per sub requirement (kbps) = 12.43 * 0.2 = 2.486
Uplink Cell carrier capacity (Kbps) = 1607.17</td></tr>
<tr><td colspan="4">Downlink Cell carrier capacity from uplink and down link budget (Gbps)</td><td colspan="4">Downlink Cell carrier capacity from uplink and down link budget (Kbps)</td><td colspan="4">Uplink Cell carrier capacity by estimation from DL capacity (Kbps)</td></tr>
<tr><td colspan="4" align="center">3.14</td><td colspan="4" align="center">3214.34</td><td colspan="4" align="center">1607.17</td></tr>
<tr><td colspan="12"> cell capacity estimation (Subscriber /cell) Total Up link carrier capacity (sub/cell) = 1607.17/ 2.486 = 646
Active Up link carrier capacity sub/cell = 646 * 0.7 = 452</td></tr>
<tr><td colspan="3">Active Down load carrier capacity (sub/cell)</td><td colspan="3">Total down load carrier capacity sub/cell</td><td colspan="3">Active Up load carrier capacity (sub/cell)</td><td colspan="3">Total Up load carrier capacity sub/cell</td></tr>
<tr><td colspan="3" align="center">275.19</td><td colspan="3" align="center">393.12</td><td colspan="3" align="center">550.37</td><td colspan="3" align="center">786.25</td></tr>
</table>

The result can be compared with one of UMTS site which deployed where ever the country other than border town. But the site needs to have the same morphology, network configuration and capacity as UMTS site at Togowchale. This site is selected to be Alemaya/ Haramaya with site ID 141034 which deployed at Alemaya/ Haramaya town.

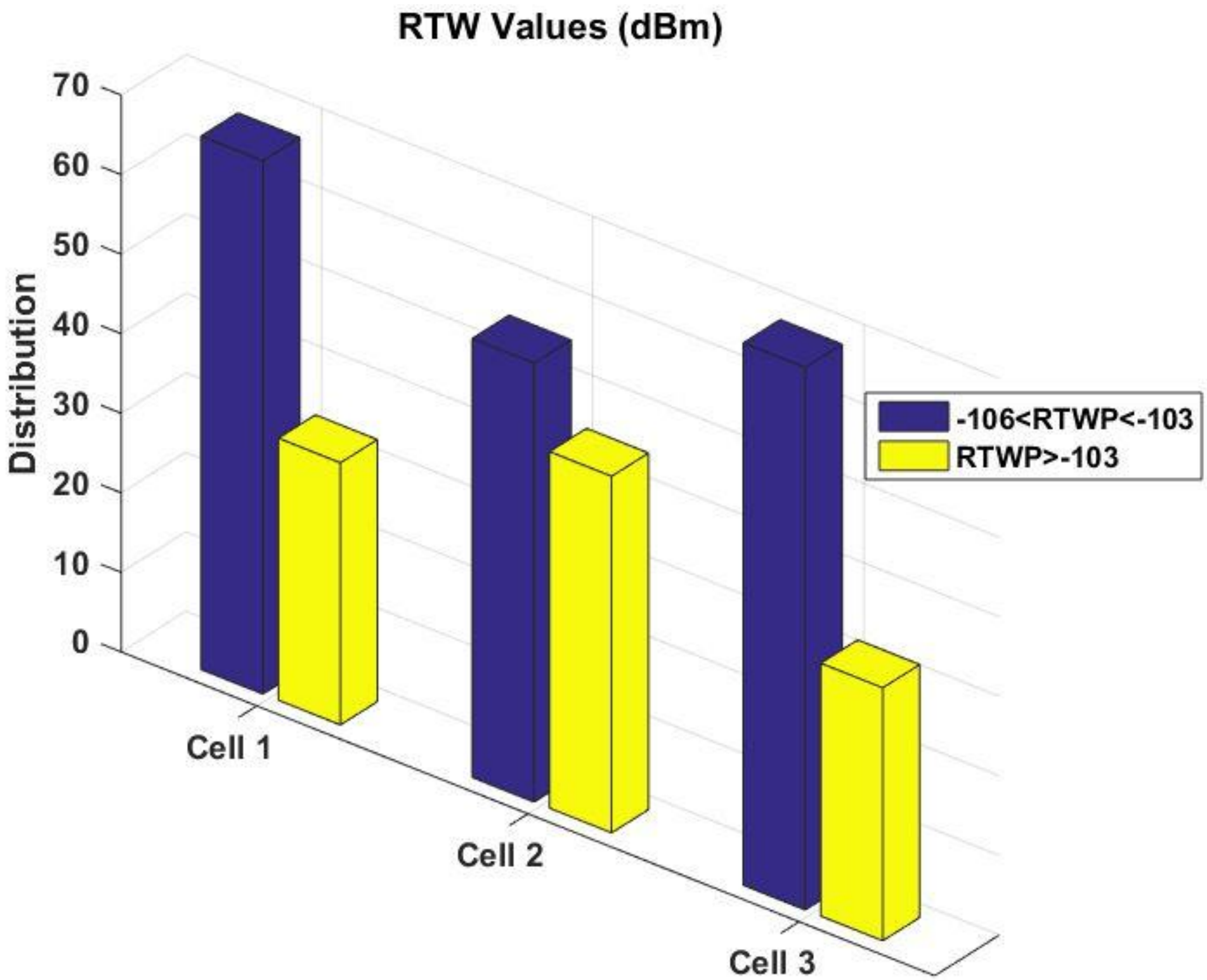

Figure 5.8: RTWP values of the site with ID 141034

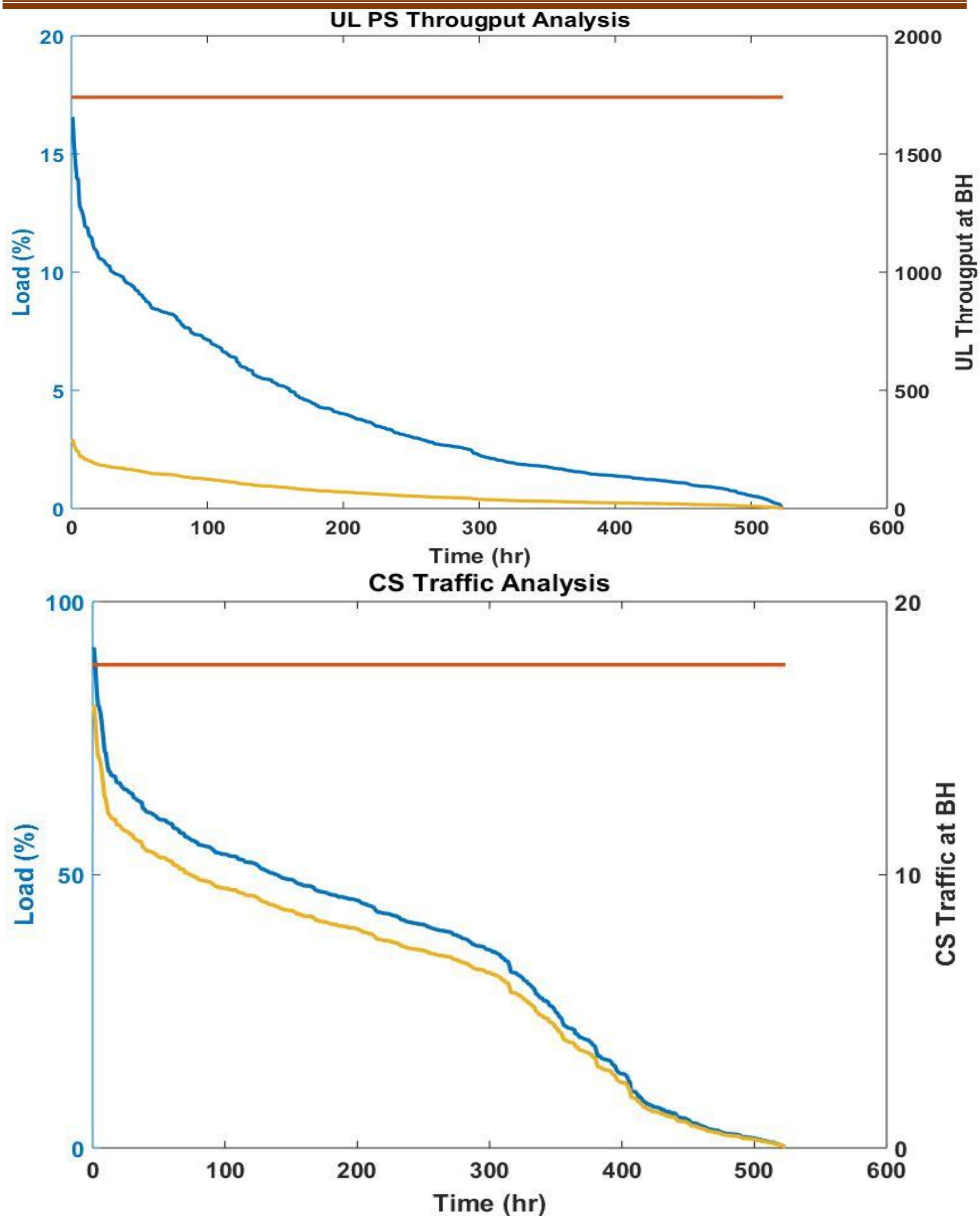

Figure 5.9: Offered and carried Busy hour CS PS traffic for the site 141034

The comparison results show that

Average RTWP of Togowchale UMTS site = -100 dBm

Average RTWP of Alemaya UMTS site = -105 dBm

The PS throughput of 17% of the design capacity recorded with the rise over thermal or noise rise of 1dBm for Alemaya site where as for Togowchale case only 14% can be achieved with much higher noise rise which is equal to -100dBm.

5.6. Summary of capacity loss analysis

The two methods of load estimation show

- The RTWP analysis indicate that a cell is over loaded much higher than the optimum load of 75% (-106 < RTWP < 100) dBm

- The throughput-based load analysis at busy hour traffic compares the designed capacity with measured (carried) shows that a cell is underutilized. The maximum of 14% of HSUPA throughput can be achieved.

- As shown in figure 5.5, the average distribution of RTWP values of the three cell which is greater than -100 dBm is 50%, meaning that for a half of the month duration this site is performing with a loading factor (η) greater than 0.75.

- **The comparison result can tell us that the extra loading which makes the cell to have such RTWP values or performance is due to cross boarder uplink interference coming from users of Somaliland operators.**

Justification

Almost all ethio telecom users are captured by Somali land operators (Telesom) best service benefits

- Best quality of signal
- Less tariff
- Availability of SIM and Voucher cards

The CS traffic has better performance as compared to PS traffic this because user has much tendency to call or send SMS to others through Ethio telecom networks. The offered capacity is designed for a site which can be practically achieved and compared with the actual measured traffic capacity, 5 % of CS traffic and 70% of PS traffic is a Loss.

5.7. Loss of Revenue

In this section estimate the loss in revenue due to capacity reduction or resource underutilization caused by external interference. In order to calculate the loss revenue, the charge for a consumer to use mobile services provided by Ethio telecom has to be Known. The charge for using mobile services for consumers is dependent on their usage. The desired usage for a consumer can be matched to a mobile tariff, where the mobile tariff has a charge for the consumer for using voice, SMS and internet data services. The tariffs vary from peak time and peak off time. Peak time is (morning 1:00 am to 4:00 pm night) local time. Peak off time is (night 4:00 pm to 1:00 am morning). Circuit switched (CS) and packet switched (PS) busy hour (BH) traffic over the period of a month is then used to make the analysis simple.

National call Service charging tariff (prepaid and postpaid)

(CDMA, GSM, WCDMA (3G) & LTE(4G) mobile usage tariff (prepaid and postpaid)

- Peak time charge/Minute = 0.5
- Off Peak time charge/Minute = 0.3
- Data service usage price = 0.35 Birr/MB

The Revenue function Z = AX + BY shown in figure 5.10 was used in MATLAB with variables X equal to CS traffic loss in Minutes and Y equal to PS traffic loss in MB, with the Z variable equal to cost which is representative of the revenue lost.

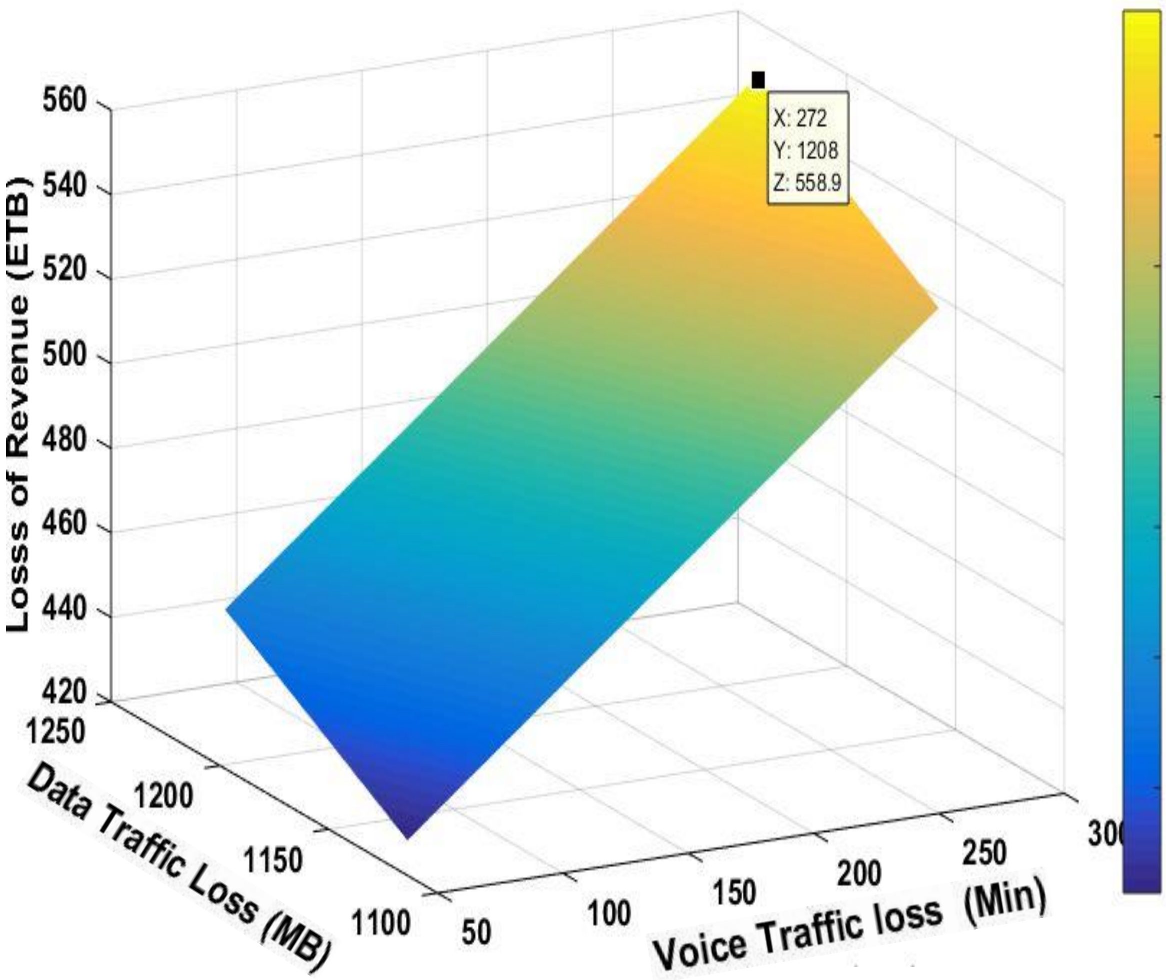

Figure 5.10: Revenue function showing the loss with respect to voice and data services

Chapter 6

Conclusion and Recommendation

This chapter commences with a summary of the work done in this study and is concluded with some recommendations and ideas for future studies.

6.1. Thesis summary

The problem area is introduced in Chapter 1 and the significance of doing a study in valuable contribution towards the awareness of how interference of another operator's network (which we can' t control) affects the performance of the network at boarder town. The objectives are set out, namely identifying cross boarder interference and more importantly analyze the impacts on capacity and measure the associated loss on revenues for UMTS mobile network deployed at the border town of Togowchale. It was identified that various factors contribute to the uplink capacity degradation of UMTS network. and that these factors impact on the performance of the network.

In Chapter 2 insightful knowledge into the 3G UMTS technology is provided. UMTS system architecture, WCDMA system overview and Multiple access methods were discussed, as these are the basic blocks to understand the 3G mobile network. Revenue and the method of reporting, in particular wireless communication system was also highlighted. The uplink capacity of UMTS in relation with HSPA evolution functionalities were discussed in Chapter 3. The common types of interference were elaborated. Chapter 3 focuses on attainment of the first objective, identifying a source of intra cell interference for further analysis which was presented in chapter 4.

In Chapter 4 a model for the measurement of uplink capacity with various factors and using the two methods for the analysis of the impacts of interference on the capacity was introduced. This chapter focuses on attainment of the primary objective introduced in Chapter 1, namely to estimate the loss in revenue due to capacity degradation because of the impacts of cross border interference. For the first part of the assignment analytically using mathematical model capacity was calculated with and without interference and the capacity loss was measured. The second assignment was the analysis of uplink load using algorithm proposed by Holma. For this case with the approach presented by Holma the uplink load was calculated from the measured RTWP and throughput values.

6.2. Suggestions and recommendations

The goal set out to achieve, in writing of this thesis was primarily to analyze the impact of interference on the uplink capacity of 3G network and, as a result, be able to estimate the capacity loss and quantify this loss in terms of a company revenue. To perform that study WCDMA capacity model and algorithm were used. The analysis was performed using MATLAB, for different scenarios, and different parameters. In this thesis system model and problem-solving approaches is divide in two different parts. The first one is calculations of capacity under different scenarios and calculation models were applied. the second part, is also about load analysis using RTWP and network traffic load. Starting on the capacity calculation the minimum allowable receiver power was found out to be the most important indicator because it reflects number of users which can be served in uplink scheme.

Cross boarder interference a common issue for Ethio telecom as there exist in every direction of the border town. In general, major commercial activities develop at the various borders of towns in Ethiopia. Consequently, the areas along the border generally constitute a real market for Ethio telecom. The situation on this specific town as observed during data collection phase found to be a serious problem because the following reasons Almost all Ethio telecom users

(75%) are captured by Somaliland operator networks best quality of signal, tariff motivation and availability of voucher and SIM cards. This problem can be seen in to two perspectives, from the point of Technical and Economic aspects

Economic aspects

In reality, the penetration of Somaliland mobile networks into Ethiopia poses the problem of protecting the revenues of Ethio telecom. On the market, it is to be noted that Ethio telecom consumers subscribe to a Somaliland mobile network by buying the corresponding chip, or use the services of a Somaliland mobile network.

Technical Aspects

From the Engineering point of view what matters is the interference that occurred on the network elements due to the usage of the same set frequency between the two operators for different technologies. To see indirect impacts of interference on revenues, it is essential to first measure the capacity loss using scientific approaches on the field.

6.3. Possible future work

As future guidelines for a continuous development of the scope of this thesis, several suggestions can be made. Regarding the scenario definitions, and its limitations, it could be further developed, in order to include the impacts of interference on downlink capacity and coverage. It could also be considered the use of real scenarios, based on real maps and user distribution. One other direction would be the analysis of the inter cell interreference in small cell deployment scenario of LTE networks.

References

[1] Tanveer ul Hag "Mitigation of External Interference on an EGSM Network ", 1wi- tribe, N-14, F-8 Markaz, Islamabad, Pakistan

[2] Mark Fe´legyha´zi et-al "Border Games in Cellular Networks", Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB), University of Split, Croatia

[3] H. Holma and A. Toskala, "Introduction to WCDMA," in *WCDMA for UMTS*, 5th Edition, A John Wiley and Sons, Ltd., Publication, 2010, pp. 39-260

[4] F. Ma´rk, C. Mario, D. Diego, H. Jean-Pierre, "Border Games in Cellular Networks", Laboratory for computer Communications and Applications (LCA) EPFL, Switzerland, *IEEE INFOCOM* 2007.

[5] Muhammad Suryanegara et al. "The Interference on WCDMA System in 3G coexistence network", Personal, Indoor and Mobile Radio Communications (PIMRC'06), *IEEE International Symposium*, 2006

[6] Lukas Klozar et al. "Effect of Co-Existence Interferences on QoS of HSPA/WCDMA Mobile Networks, "in *Proc. of the 23th Conference Radioelektronika,* Pardubice, Czech. Republic, 2013, April 16-17

[7] S.M et al. "Up link Capacity of ALL -Packets- Service WCDMA Mobile Internet System in EMI Environment "in *Proc. IEEE International Symposium*, 2004

[8] Wen-Tzu Chen and Jyun-Ting Lin, "Analysis of the Impacts of Uplink Co-channel Interference on Cell Coverage in an IEEE 802.16m System", *IEEE Trans. Veh. Technol*, vol. 63, no. 5, 2014, pp. 2208–2215.

[9] Lina Lan et al. "GSM Co-Channel and Adjacent Channel Interference Analysis and Optimization", *ISSN TSINGHUA Science and Technol*, vol. 16, no. 6, December 2011, pp. 583–588,

[10] H. A. Abdureshid. (2016). The two-edge knife of Togochale immigration office [Online] **Available** FTP: Somalilanddisporanews.com

[11] Ethio Telecom, "Drive Test and optimization report," Elect. Eng. Optimization office, ethio Telecom. Addis Ababa, Aug. 22, 2018

[12] David Tse and Pramod Viswanath, "Fundamentals of wireless Technology", Cambridge University Press, pp. 120-153. 2005

[13] Qualcomm University, "An Introduction to UMTS (WCDMA), "

[14] ECC/CEPT, 'Compatibility Study for UMTS Operating Within the GSM 900 and GSM 1800 Frequency Bands'

[15] Heiska, K., "On the Modelling of WCDMA System Performance with Propagation Data", Dissertation *for the degree of Doctor of Science in Technology, Department of Electrical and Communications Engineering*, Helsinki University of Technology, Espoo, Finland, 23 April 2004

[16] Laiho, J., Wacker, A., Novosad, T. (editors), "Radio Network Planning and Optimization for UMTS," John Wiley&Sons, Ltd, 2001, 484 p.

[17] Sipilä, K., Laiho-Steffens, J., Wacker, A. and Jäsberg, M., "Modeling the impact of the fast power control on the WCDMA uplink," Proceedings of VTC 1999 Spring Conference, Houston, Texas, May 1999, pp. 1266-1270.

[18] KOKKO J, 2000, Mobile Internet charging: pre- paid vs. Post- paid, Networking Laboratory, HUT, pp. 2.

[19] COMPTROLLER‟S HANDBOOK, 1998, Emerging Market Country Products and Trading Activities, Administrator of National Banks, pp. 4.

[20] X. Geng and A.B. Whinston, Profiting from Value-Added Wireless Services, *IEEE Computer 34*, August 2001, pp. 87-89.