ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING

DEPARTMENT

UMTS Coverage and Capacity Planning for the case of Bole Sub City in Addis Ababa

By: Lejalem Mitikie
Advisor
Dr.-Ing. Dereje Hailemariam

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Communication Engineering

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Lejalem Mitikie

Approval by Board of Examiners

Chairman, Dept. Graduate Committee	Signature
Dr.-Ing. Dereje Hailemariam Advisor	Signature
Internal Examiner	Signature
External Examiner	Signature

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.

Lejalem Mitikie ____________________

Name Signature

Place: Addis Ababa

Date of Submission: _________________

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

Dr.-Ing. Dereje Hailemariam _______________

Advisor's Name Signature

Abstract

The modern mobile communication technology has experienced generations and evolved into the Fifth generation which is ongoing with pre-commercialization. In addition to the market demand, the limitations in previous generation trigger a motivation for developing latest mobile technologies. For instance the limitations in Second Generation (2G) system like: limited and low utilization of frequency spectrum and weak support for mobile multimedia services was the motivation behind the evolution of the Third Generation (3G) mobile technology. Therefore, the 3G is a natural result in the advancement of the 2G mobile Communications. The 3G communication technology opens the door to a brand new mobile communication world. In addition to clearer voice services, it allows users to conduct multimedia communications with their mobile terminals.

In order to benefit from this technology we need to have a well-designed and planned state-of-the art network. For the case of Ethiopia, EthioTelecom is doing massive expansion projects to address strong requirement of voice and data services with adequate network capacity and coverage.

Thus, this thesis focuses on carrying out Universal Mobile Telecommunication System coverage and capacity planning taking Bole sub City of Addis Ababa as a case study. Dimensioning and Prediction simulation output verifies that, the intended planning and design work for the designated area can be achieved with 105 node B, which is less by 8 NodeBs compared to the existing 3G radio network system.

Key Words: UMTS; Coverage planning; Capacity Planning.

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I would like to express my deep sense of gratitude to my Advisor Dr. -Ing. Dereje Hailemariam, for his invaluable guidance and encouragement in carrying out my thesis work. Besides I am highly indebted to my friend and Co-worker Mr. Kifle Berhane, who has given me all the necessary technical guidance and support.

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Abbreviations

A-DCH	Associated Dedicated Channel
AG	Access Gateway
AICH	Acquisition Indication Channel
AMR	Adaptive Multi Rate
AP	Access Point
BSC	Base Station Controller
BTS	Base Transceiver Station
CBD	Central Business District
CCH	Control Channel
CD/CA-ICH	Collision Detection/Channel Assignment Indication Channel
CE	Chanel Element
CS	Circuit switched
CSICH	CPCH Status Indication Channel
DBS	Distributed Base Station
DCCH	Dedicated Control Channel
DCHSDPA	Dual Cell High Speed Downlink Packet Access
DT	Drive Test
DTX	Discontinuous Transmission
EDGE	Enhanced Date rates for GSM Evolution
EDGE+	EDGE Plus (EDGE Evolution)
EICC	Enhanced Counteraction Combining
FANR	Fast ACK/NACK Reporting
FDD	Frequency Division Duplex
GGSN	Gateway GPRS Support Node
GMSK	Gaussian Minimum Shift Keying
GPRS	General Package Radio Service
GSM	Global System of Mobile communications
HGW	Home Gateway
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access

HS-DSCH	High Speed Downlink Shared Channel
HSPA	High Speed Packet Access
HSPA+	High Speed Packet Access Plus
HS-SCCH	High Speed Shared Control Channel
HSUPA	High Speed Uplink Packet Access
IBS	Indoor Base Station System
ICC	Interference Counteract Combine
Iub	Iub Interface
KPI	Key Performance Index
LTE	Long Term Evolution
MAIO	Mobile Allocation Index Offset
MGW	Media Gateway
MIMO	Multiple Input Multiple Output
MOS	Mean Opinion Score
MR	Measurement Report
MS	Mobile Station
MSC	Mobile Switching Centre
MSC Server	Mobile Switching Center Server
MSRD	Mobile Station Receive Diversity
O&M	Operation and Maintenance
OAM	Operations, Administration and Maintenance
P-CPICH	Primary Common Pilot Channel
PLMN	Public Land Mobile Network
PS	Packet Switched
PSTN	Public Switched Telephone Network
RNC	Radio Network Controller
RRC	Radio Resource Controller
RRU	Radio Remote Unit
RSCP	Received Signal Code Power
Rx	Receiver
SAE	System Architecture Evolution
SeGW	Security Gateway

SGSN	Serving GPRS Support Node
SRB	Signaling Radio Bearer
TDD	Time Division Duplex
TTI	Transmission Time Interval
Tx	Transmit
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
UTRAN	UMTS Terrestrial Radio Access Network
VOD	Video on Demand
WRC	World Radio-communication Conference
16 QAM	16 Point Quadrature Amplitude Modulation
32 QAM	32 Point Quadrature Amplitude Modulation
3GPP	Third Generation Partnership Project
64QAM	64 Quadrature Amplitude Modulation
8 PSK	Eight - Step Shift Keying

Chapter 1 Introduction

Initially, mobile communication technologies were developed separately, as various countries and technical organizations continued to develop their own technologies. On one hand, this situation helped to meet the needs of the users at the early stage of mobile communication and expand the mobile communication market, on the other hand, it created barriers between regions and made it necessary to unify the mobile communication systems globally. Under such a context, International Telecommunication Union (ITU) launched the standardization of the 3G mobile communication system in 1985 [1].

It adopts a structure similar to the second generation mobile telecommunication system, including the Radio Access Network (RAN) and the Core Network (CN). The RAN is used to process all the radio-related functions, while the CN is used to process all voice calls and data connections within the Universal Mobile Terrestrial System (UMTS), and implements the function of external network switching and routing. Logically, the CN is divided into the Circuit Switched (CS) Domain and the Packet Switched (PS) Domain. UMTS Terrestrial Radio Access Network (UTRAN), CN and User Equipment (UE) together constitute the whole UMTS system.

Compared with the existing 2G system, the 3G system has the following characteristics [1]:

- Support for multimedia services, especially Internet services.

- Easy transition and evolution.
- High frequency spectrum utilization.

Network planning refers to the process of designing a network structure and determining network elements subject to various design requirements. Network planning is associated with network dimensioning and detail coverage and capacity planning [2]. Unlike the 2G, UMTS network planning is rather complicated, because many system parameters are closely related to each other and should be calculated at the same time. As for radio network planning, in any case, it is required to calculate the link budget, coverage, capacity, number of Node B's, and estimated coverage of base stations. In addition, it is required to design the whole network, calculate the number of channel elements, capacity of transmission lines, Radio Network Controllers (RNC), Mobile Station Controller (MSC) and other units in a base station.

In network planning, performance measurements such as dropped call rate and grade of service (GOS) should be introduced to measure the network performance. The coverage can be designed as continuous coverage or hotspot coverage. We should estimate coverage of base station carefully according to different services and different implemented policies.

In UMTS, the downlink capacity is considered more important than the uplink capacity because the asymmetrical traffic is closely related to download services. In UMTS, more consideration is given to the downlink capacity. The factors causing the differences between the capacity uplink and the downlink capacity are the orthogonal code and the BS transmits diversity [2]. Wideband Code Division Multiple Access (WCDMA) system adopts long extended code to distinguish cells in the downlink and subscribers in the uplink [3].

As already mentioned, UMTS planning has a huge interest and importance to the mobile world, and it is the main objective of this thesis. In order to accomplish this goal, some vital steps must be accomplished, like the study of UMTS network radio air interface, services and applications definition and characterization, system simulation, and traffic prediction.

1.1 Problem Statement

In Ethiopia massive telecom expansion projects are undergoing all over the country. These kinds of projects need qualified and dynamic professionals in the field of network planning and design areas. Even though 3G network is already deployed in Ethiotelecom network, there will always be an expansion projects to satisfy an ever increasing user demand for various kind of services and mobile applications. However, most of the time due to the professional gap, network planning and design works are done by vendors. So, the core motivation behind this thesis is to verify if already implemented number of Node B's can satisfy the required input coverage, capacity and signal strength value set by Ethiotelecom, taking Bole sub city as a case study and at the same time to understand UMTS coverage and capacity planning and design principle and methodologies to be used in coming expansion projects, so as to save the planning and design cost. As an example let us take the average cost per site which is paid for planning and design work is around 30,000 Birr. Currently EthioTelecom is having around 9313 sites, that means the total cost becomes 20,000*9313Birr = 186,260,000 Birr. Hence we could have saved this much amount of money if we could have the technical and professional capability this job requires.so these are the motivations behind this thesis work.

1.2 Objectives

1.2.1 General Objective

The main objective of this thesis is to carryout UMTS radio frequency (RF) coverage and capacity planning with high quality of voice and data services taking Bole sub City of Addis Ababa as a case study.

1.2.2 Specific Objective:

- Understanding UMTS mobile technologies and its evolution that includes understanding its similarity and difference with 2G system, architecture, interface technology, basic network structure, protocol structure and offered services.
- To understand, procedures and mechanisms for coverage and capacity planning in UMTS system and set out design guidelines.
- Get familiarized with the input and output parameters which are needed in the planning phase.
- To design a UMTS radio access network which can provide sufficient coverage over the entire service area, to ensure high quality voice services and data services.

- To enable an economical network implementation when the service is established and a controlled network expansion during the life cycle of the network.

1.3 Contribution

This thesis can be used by network planners and consultants even by operators to be used as a design document and guideline for future network expansion projects and even for optimization activities of the existing network.

1.4 Literature review

Planning and design of a UMTS radio access network has been studied from different perspectives. This subtopic aims to cover some of the literatures closely related to UMTS Coverage and capacity planning technique of UMTS radio access network.

Author Amaldi,E.[4] studied the Radio planning problem by considering uplink and downlink directions separately and proposed an algorithm and mathematical programming model for locating and configuring Node B's and maximize coverage and minimize cost of UMTS networks. Reduce drastically the computation time.

A full UTRAN network solution is developed by Noblet,C.M.H.,Ruedat,R.et.al.[5], by modeling the full UMTS protocol stack including the major characteristics of the UTRAN transport layer, this tool can undertake a huge variety of activities, such as algorithm testing and optimization, protocol parameter tuning, buffer sizing, network link dimensioning, traffic growth scenario analysis, and performance optimization.

Which will be used in system simulations and modeling activities to ensure optimum network performance and integrity.

Clark,G;Ling,Y.K.[6] Examines the requirement and standards for transport with in the 3GPP release 99 ATM based UMTS Terrestrial Radio Access Network (UTRAN) and presents a number of Solution Architecture that addresses these requirements. This will solve the associated provision and optimization of transport capacity to link these sites to the controller and switching sites.

Eisenblatter,A.;Geerdes,H.F.[7]Introduced planning methodologies that allow minimizing interference overhead while maintaining the established network coverage. Their main contribution is the first practicable approach for comparing interference to lower bounds and benchmarks. This comparison on realistic datasets suggests that their optimization methods produce first-class results. This will greatly improve capacity planning and optimization with minimal interference.

Jamaa,S.B.[8] Presented a combined coverage and capacity optimization methodology for automatic cell planning of UMTS networks. An automatic cell planner (ACP) based on a multi objective genetic algorithm (GA) that simultaneously and separately optimizes the different objectives is described. This ACP is of particular interest in cases where coverage objectives are difficult to achieve using a manual design process, for hilly environment or for rollout scenarios with some unavailable sites.

Jamaa,S.B.[9] Developed a Multi-objective genetic algorithm (adaptive heuristic search algorithm based on the evolutionary ideas of natural selection) for automatic cell planner tool. Automatic cell planning aims at optimizing coverage, capacity and quality of service by automatically adjusting antenna parameters and common channel powers.

In certain cases, coverage and capacity can be antagonistic criteria, and their aggregation in a single cost function may turn out to be inefficient. Such a scenario may occur when the environment is hilly, when certain sites are unavailable, and in general, when coverage objectives are difficult to achieve using a manual design process. To tackle this difficult and challenging problem, a multi-objective genetic algorithm has been developed and utilized as the optimization engine of the automatic cell planner (ACP). And the efficiency of the ACP is highly improved.

Eduard,A.F;Garzon,H.F. [10] Verified the behavior and influence of an algorithm about packets and control of power and handover in UMTS network with traffic background through simulation of different scenarios by using OPNET simulation modeling tool. In order to guarantee and appropriate Quality of service some algorithms of Radio Resource Management (RRM) have been created which are responsible for the efficient use of the air interface.

Britvic,V.[11] Described the necessary steps in UMTS Network design which are essential for efficient network deployment and ongoing business growth, by taking in to consideration the broad end-to-end operation of end-user services and applies this to a network solution. Radio design, transport, core, signaling and synchronization are some of the key considerations in the development of an effective design.

Hafez,H.[12] Proposed various Scrambling code allocation schemes that assign the codes according to the planner needs. In addition, a detection algorithm of SC clashes1 has been developed and the recommended assignment is then proposed to decrease the overall interference. Their results were applied to a live WCDMA cellular network and they achieved performance improvement.

The project by M.Hemanth,et.al[3] involves the basic study of GSM and CDMA architecture along with planning and design of a 3G radio network in a particular area using Atoll Rf planning software. In their mini project, they successfully planned the UMTS radio network for Gachibowli region with los bit error rate and low blocking probability.

1.5 Thesis Layout

The thesis work is organized in such a way that it gives seamless flow and understanding regarding coverage and capacity planning for UMTS. Chapter one talks about the objectives, scope, contribution, methodology, statement of the problem along with a short introduction. Whereas Chapter two is about the theoretical fundamentals of UMTS and some of its key technologies and Chapter three, four and five focuses on the nominal planning process of UMTS including coverage and capacity planning. The practical radio network planning prediction results along with conclusion and recommendation are presented in chapter six.

1.6 Methodology

The radio network planning process can be divided into different phases. The first step is the Preplanning or initial phase. In this phase, the basic general properties or requirements of the future network are collected and investigated, for example, what kind of mobile services will be offered by the network, what kind of requirements (coverage and traffic model) does the different services impose on the network will be collected and analyzed in this phase.

The Next phase is where the larger portion of the planning work will be done. A site survey will be carried out on an about to-be-covered area, and the possible site locations of Node B's are identified. All the data related to the geographical properties and the estimated traffic volumes at different points of the area will be incorporated into a digital map. Based on the selected propagation model, the link budget will be calculated. There are some important parameters which impacted the link budget, for example, the sensitivity and antenna gain, cable loss; fade margin etc. using the digital map and the link budget, simulations will evaluate the different possibilities to build up the radio network.

The main goal is to achieve best coverage with optimal capacity, while reducing the costs as much as possible. The coverage and the capacity planning are of essential importance in the whole radio network planning. The objective of coverage planning is to determine the service range whereas that of capacity planning is to determine the number of Node B's and their respective configuration type.

In the third phase, continuous modification will be made to optimize the final network planning result. The simulated results will be examined and refined until the best compromise between all of the facts is achieved. Then the final radio plan will be deployed.

Chapter 2 Universal Mobile Telecommunication System

2.1 Introduction

Mobile communication has experienced different generations and currently evolved into the fifth generation, which is ongoing with pre-commercialization. The first generation is the analog cellular mobile communication network in the time period from the middle of 1970s to the middle of 1980s [1].

The main feature of the first generation mobile communication systems is that they use the frequency reuse technology and adopt analog modulation for voice signals. However, the limitations are:

- Low utilization of the frequency spectrum.
- Limited types of services.
- No high-speed data services.
- Poor confidentiality and high vulnerability to interception and number embezzlement.
- High equipment cost.

- Large volume and big weight.

To solve these fundamental technical limitations of the analog systems, the digital mobile communication technologies emerged and the second generation mobile communication systems represented by Global System for Mobile Communications (GSM) came into being in the middle of 1980s [1].

Put forward in 1985 by the International Telecommunication Union (ITU), the 3G mobile communication system was called the Future Public Land Mobile Telecommunication System (FPLMTS) and was later renamed as International Mobile Telecommunication-2000(IMT-2000) [1]. The 3G mobile communication system is a kind of communication system that can provide multiple kinds of high quality multimedia services and they are compatible with the fixed networks.

An increase in user demand have triggered researchers and industries to develop a new mobile communication system called fourth generation (4G) which can provide multi-service capacity by integrating all the mobile technologies aiming to have a common platform for all the technologies that have been developed so far. In 4G the functionality of the RNC and BSC is distributed to the e-node B and a set of servers and gateways, which makes it less expensive.

The Fifth generation (5G) is expected to be, the future of mobile communication. Its radio access will be built upon both new radio access technologies (RAT) and evolved existing wireless technologies like LTE, HSPA, GSM and WiFi. To implement connectivity for a wide range of applications the capabilities of 5G wireless access must exceed far beyond previous generations. These capabilities include very high achievable data rates, very low latency and ultra-high reliability [13].

Below is comparison between different generations of mobile technologies in regard to standards, technology, Service type, multiplexing methods and switching methods.

Technology	1G	2G,2.5G	3G	4G	5G
Start /Deployment	1970 /1984	1980 /1999	1990 /2002	2000 /2010	2010 /2015
Data rate	2kbps	14.4-64kbps	2Mbps	200Mbps to 1Gbps	1Gbps and higher
Standard	AMPS	CDMA GSM GPRS EDGE	WCDMA, CDMA2000	Single unified standard	Single unified standard
Technology /feature	Analog	Digital	broad bandwidth CDMA,IP	Unified ip , LAN/WAN WLAN.	Unified ip, LAN/WAN/ WLAN ,www
Service	voice	voice,	Integrated higher	Dynamic information	Dynamic information

Technology	1G	2G,2.5G	3G	4G	5G
		SMS, higher capacity in packetized data	quality audio, Video and data.	access wearable devices	access wearable devices with all capabilities.
Switching	Circuit	Circuit, except core and data	packet except air interface	all packet	all packet
Core	PSTN	PSTN	packet	internet	internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal and Vertical	Horizontal and Vertical

Table 2. 1: Comparison among different mobile technologies [1].

2.2 IMT2000 Frequency Band Allocation

In 1992, World Radio-communication Conference (WRC-92) allocated the frequency bands for the 3G mobile communication, with a total bandwidth of 230 MHz, as shown in Figure 2.1

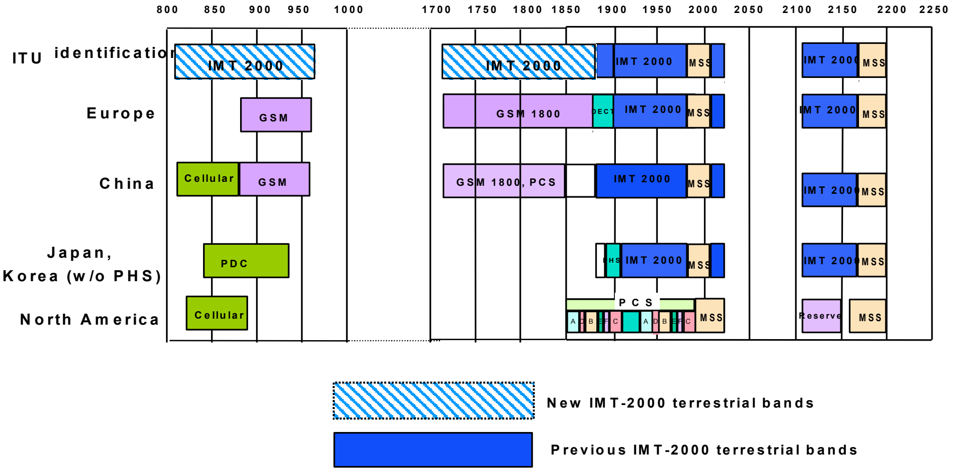

Figure 2. 1: Frequency spectrum allocation [14].

At WRC92, ITU planned the symmetric frequency spectrum resources of 120MHz (1920MHz ~ 1980MHz, 2110MHz ~ 2170MHz) for use by the FDD, and asymmetric frequency spectrum resources of 35MHz (1900MHz ~ 1920MHz, 2010MHz ~ 2025MHz) for use by the TDD [14].

At WRC2000, the 800 MHz band (806MHz ~ 960MHz), 1.7GHz band (1710MHz ~ 1885MHz), and 2.5GHz band (2500MHz ~ 2690MHz) were added for use by the IMT-2000 services [14]. These two combined make the future spectrum for 3G reach over 500 MHz, reserving enormous resource space for future applications.

2.3 Ethiopian Frequency Distribution

Figure 2. 2: Sample Ethiopian frequency allocation [15].

3G Mobile network frequency range available in Ethiopia is from 1700 MHz to 2690 MHz of which 2140 MHz for downlink and 1950 MHz for uplink are used by Ethiotelecom UMTS radio network.

As we can see from the above table the frequency range allocated for Ethiotelecom is a scarce resource, which we should bear it in mind in our planning work. We may not be able to get the flexibility to use whatever frequency resource we need during the planning work and at the same time we have to consider also the interference we may face from neighboring frequency ranges.

2.4 WCDMA Services

Compatible with abundant services and applications of GSM and GPRS, the WCDMA system has an open integrated service platform to provide a wide prospect for various 3G service.

2.4.1 Categories of 3G Services

- Basic telecom services, including voice service, emergency call service and SMS.
- Supplementary services, the same as the supplementary services defined in GSM.
- Bearer services, including circuit bearer service and packet bearer service.
- Intelligent service, an intelligent network service based on CAMEL mechanism inherited from the GSM system.
- Location services, services related to location information, such as charging by area, mobile yellow page and emergency locating.

- Multimedia services, including circuit real-time multimedia service, packet real-time multimedia service and non-real-time store-and-transfer multimedia message service.

The above services are roughly classified. Actually these services may overlap. For example, charging by area is not only a location service, but also an intelligent service.

2.4.2 Features of 3G Services

3G (WCDMA) services are inherited from 2G (GSM) services. In a new architecture, new service capabilities are generated, and more service types are available. Service characteristics vary greatly, so each service features differently. Generally, there are features as follows:

- The real-time services such as voice service generally have the QoS requirement.
- Compatible backward with all the services provided by GSM.
- The concept of multimedia service is introduced.

2.5 UMTS System Structure

The Universal Mobile Telecommunications System (UMTS) is the third generation (3G) mobile telecommunication system by using the WCDMA air interface technology, usually called WCDMA telecommunication system. It adopts a structure similar to the second generation (2G) mobile telecommunication system, including the Radio Access Network (RAN) and the Core Network (CN) [16]. The RAN is used to process all the radio-related functions, while the CN is used to process all voice calls and data connections within the UMTS system, and implements the function of external network switching and routing. Logically, the CN is divided into the Circuit Switched (CS) Domain and the Packet Switched (PS) Domain. UMTS Terrestrial Radio Access Network (UTRAN), CN and User Equipment (UE) together constitute the whole UMTS system [16].

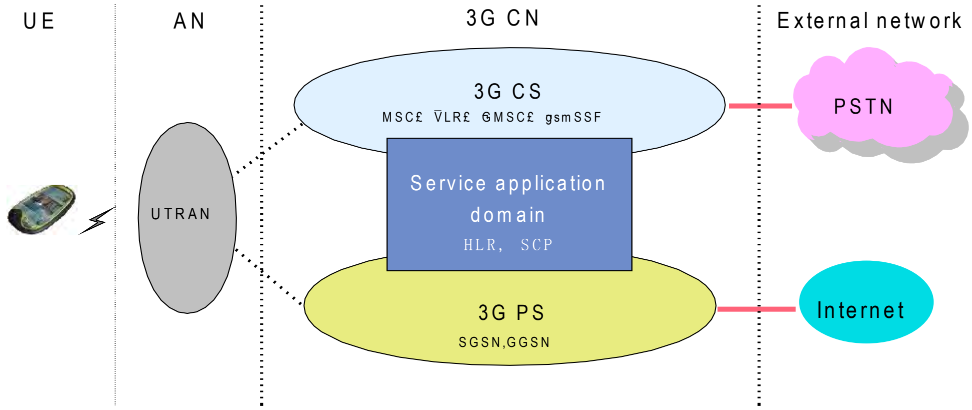

Figure 2. 3: UMTS system structure [16].

2.6 UMTS Network System Composition

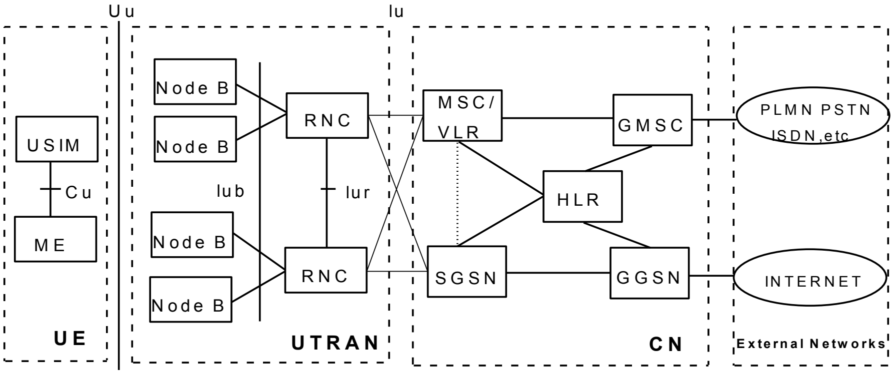

Figure 2. 4: Composition of the UMTS network system [16].

The UMTS network system includes the following parts:

User Equipment (UE): The UE exchanges data with network equipment through the Uu interface, and provides services like common voice, data, mobile multi-media and Internet application (For example, E-mail, WWW browse and FTP).

UE includes:

- Mobile Equipment (ME): Providing application and services.
- UMTS Subscriber Module (USIM): Providing subscriber identification.

UMTS Terrestrial Radio Access Network: Is divided into Node B and Radio Network Controller (RNC).

- **Node B:I**s the base station of the WCDMA system and processes the physical layer protocol of the Uu interface and interconnects with RNC via the standard Iub interface. Its main functions include spreading/de-spreading, modulation/demodulation, channel coding/decoding, and conversion between baseband signals and RF signals.
- **Radio Network Controller (RNC):** Responsible for connection establishment, call release and handover.

Core Network (CN): CN is responsible for connecting other networks as well as communicating and managing UEs. The core network equipment of different protocol versions in the WCDMA system is different. Generally, the R99 core network is divided into the CS domain and the PS domain [17]. The Release 4(R4) core network is the same as the Release 99 (R99) core network, but in the R4 core network, the MSC function of

R99 CS is implemented by the two separate entities: Mobile Switching Center (MSC) Server and Media Gateway (MGW). The Release 5 (R5) core network is the same as the R4 core network except that R5 has been added with an IP multi-media domain [16]. Currently Ethiotelecom implemented Release 5 core network.

The R99 core network has the following functional entities:

Mobile Switching Center (MSC)/ Visitor Location Register (VLR): MSC/VLR is a functional node of the CS domain in the WCDMA core network. It connects with Universal Terrestrial Radio Access Network(UTRAN)via the Iu-CS interface, with external networks such as Public Switched Telephone Network(PSTN) and Integrated Service Digital Network(ISDN) via the PSTN/ISDN interface, with Home Location Register(HLR) via the C interface, with MSC/VLR, Gateway Mobile Switching Center(GMSC) or Short Message Center(SMC) via the E interface, with Serving GPRS Support Node(SGSN) via the Gs interface[11]. Its main functions are call control, mobility management, authentication and ciphering of the CS domain.

Gateway Mobile Switching Center (GMSC): GMSC is the gateway node between the CS domain of the WCDMA mobile network and external networks, and it is an optional functional node. It connects with external networks (PSTN, ISDN and other PLMN) through the PSTN/ISDN interface, connects with HLR through the C interface [16]. It implements the routing function of incoming calls in the MSC function and inter-network settlement function of such external networks as fixed networks.

Serving GPRS Support Node (SGSN): Is a functional node of the PS domain in the WCDMA core network. It connects with UTRAN through the Iu-PS interface, with Gateway GPRS Support Node (GGSN) through the Gn/Gp interface, with HLR/AUC through the Gr interface, with MSC/VLR through the Gs interface, with SMC through the Gd interface, with CG through the Ga interface and with SGSN interface through the Gn/Gp interface and its main functions are route forwarding, mobility management, authentication and ciphering of the PS domain.

Gateway GPRS Support Node (GGSN): is a functional node of the PS domain in the WCDMA core network. It connects with SGSN through the Gn/Gp interface and with external data networks (Internet/Intranet) through the Gi interface. It provides the routing and encapsulation of data packets between the WCDMA mobile network and the external data networks [18]. Its major functions are to provide interfaces to external IP packet networks. It needs to provide the gateway function for UE to access external packet networks. From the point of view of external networks, GGSN looks as if it were a router of all user IP networks in the addressable WCDMA mobile network and it needs to exchange routing information with external networks [16].

Home Location Register (HLR): is a functional node shared by the CS and PS domains in the WCDMA core network. It connects with MSC/VLR or GMSC through the C interface, with SGSN through the Gr interface, and with GGSN through the Gc interface. And its main functions are to store subscription information for subscribers, support new services and provide the enhanced authentication function [16].

2.6.1 Basic Structure of UMTS Terrestrial Radio Access Network (UTRAN)

UTRAN includes one or several Radio Network Subsystems (RNS).A RNS is composed of one RNC and one or several node B’s. The Iu interface is used between RNC and CN while the Iub is adopted between RNC and node B, Within UTRAN RNCs connect with one another through the Iur interface [19]. The Iur interface can connect RNCs via the direct physical connections among them or connect them through the transport network. RNC is used to allocate and control the radio resources of the connected node B, however, node B serves to convert the data flows between the Iub interface and the Uu interface and, at the same time it also participated in part of radio resource management [1].

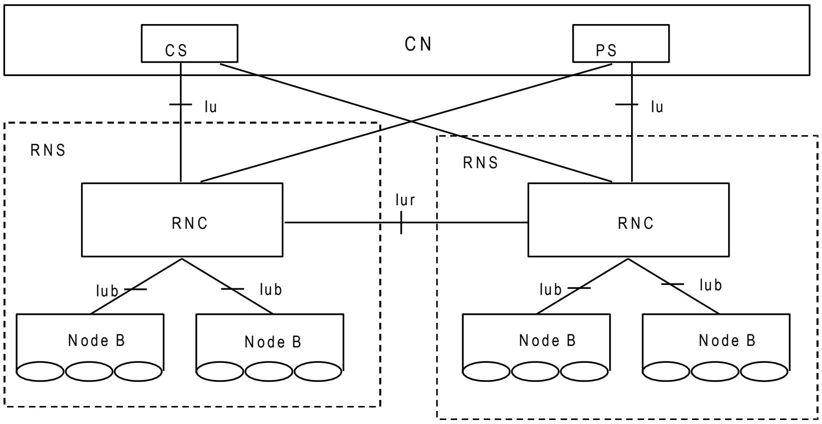

Figure 2. 5: UTRAN structure [16].

UTRAN has the following main interfaces:

Cu interface: The Cu interface is the electrical interface between the USIM card and ME, and it adopts the standard interface.

Uu interface: The Uu interface is the radio interface of WCDMA. UE accesses the UMTS system through the Uu interface, so we can say the Uu interface is the most important open interface in the UMTS system.

Iur interface: The Iur interface is the interface connecting RNCs. It is specific to the UMTS system for mobility management of UEs in RAN. For example, when different RNCs perform soft handover, all UE data are transmitted from the working RNC to the candidate RNC through the open standard Iur interface.

Iub interface: The Iub interface is an open standard interface connecting Node B and RNC. It allows RNC to connect to NodeB from another equipment manufacturer.

Iu interface: The Iu interface is the interface between UTRAN and CN. Similar to the A interface and the Gb interface in the GSM system, it is also an open standard interface. It allows different vendor's UTRAN and CN to connect together, and can be divided into the Iu-CS interface and the Iu-PS interface.

2.6.1 Basic Protocol Structure of UTRAN Interfaces

The principle of this universal protocol model design is that logically the layer and the plane should be independent; if necessary you can modify a part of the protocol structure without modifying other parts, this feature provides us the capability to made changes in a single module without affecting others.

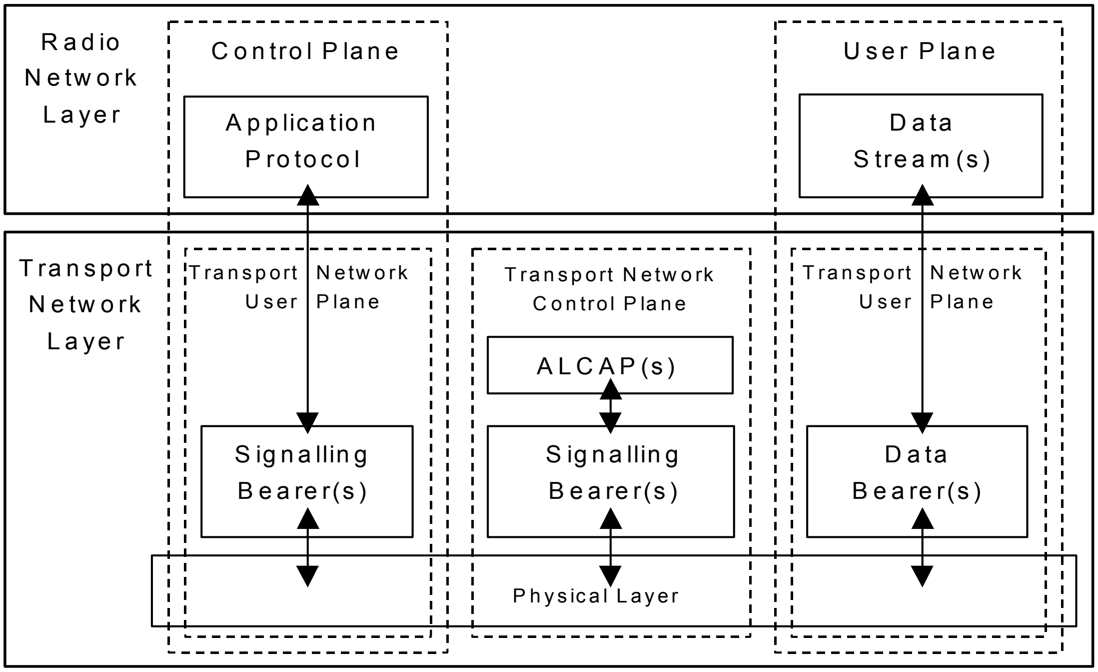

Figure 2. 6: Universal protocol model of UTRAN interfaces [13].

Horizontally, the protocol structure contains the radio network layer and the transport network layer. All protocols related to UTRAN are contained in the radio network layer. The transport network layer is the standard transmission technique adopted by UTRAN, and it has nothing to do with the specific functions of UTRAN [16].

In conclusion, UTRAN obeys the following principles.

The signaling plane is separated from the data plane. UTRAN/CN functions are separated from the transport layer that is the radio network layer doesn't depend on the specific transmission technique. Besides Macro diversity (FDD Only) is processed totally by UTRAN and the mobility management of Radio Resource Control (RRC) connections.

2.7 UMTS Radio Interface Technology

In the WCDMA system, the mobile UE connects with the system network through a radio channel on the radio interface, called Uu interface, this interface is one of the most important interfaces in the WCDMA system [20]. The radio interface technology is the core one in the WCDMA system, which shows the core technologies and main differences of all kinds of 3G mobile communication systems.

2.7.1 Protocol Structure of Radio Interfaces

From the perspective of protocol structure, the WCDMA radio interface is composed of the following three layers: Physical layer, medium access control layer and RRC layer [20]. In terms of protocol layer, the WCDMA radio interface has three channels: Physical channel, transport channel and logical channel.

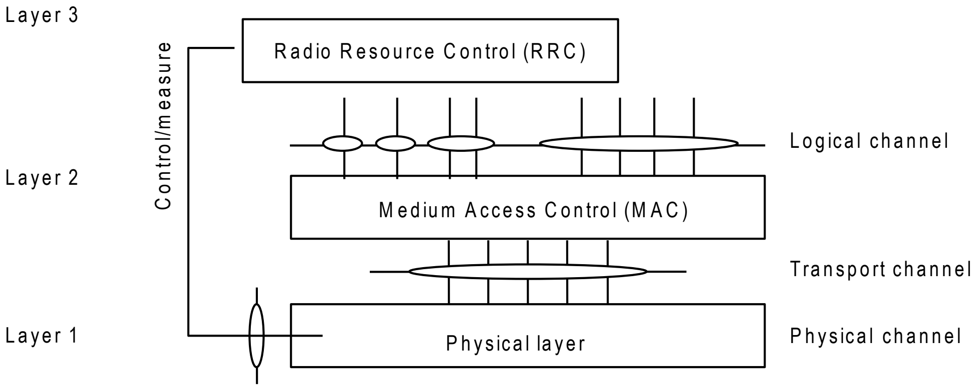

Figure 2. 7: Physical Structure of Radio Interface [20].

The circles among different layers/sub-layers in the Figure are Service Access Points (SAPs).The physical layer provides data transmission services required by the upper layer. These services are accessed by using the transport channel through MAC sub-layer.

The physical layer provides services for the Medium Access Control (MAC) layer through a transport channel, while the proprieties of transmission data determine what kind of transport channel should be used and how to transmit [21]. The MAC layer provides the RRC layer with services through a logical channel, while the proprieties of the transmitted data determine the type of the logical channel. In the MAC layer, the logical channel is mapped as a transport channel. MAC layer should select proper Transport Format (TF) for each transport channel, according to the transient source rate of logical channels.

The RRC layer configures protocol entities of lower layers as physical channels, transport channels and logical channels by using the control interfaces between it and lower layer protocols.

Logical channel: Carrying user services directly. According to the types of the carried services, it falls into two types: Control channel (for signaling and communication among different network elements) and service channel (used for transporting user traffic).

Transport channel: It is the interface of radio interface layer 2 and physical layer, and is the service provided for MAC layer by the physical layer. According to whether the information transported is dedicated information for a user or common information for all users, it is divided into dedicated channel and common channel.

Physical channel: It is the ultimate embodiment of all kinds of information when they are transmitted on radio interfaces. Each kind of channel which uses dedicated carrier frequency, code (spreading code and scramble) and carrier phase (I or Q) can be regarded as a dedicated channel [20].

At the transmitting end, the data flows from MAC and upper layers are transmitted in radio interfaces, reused and mapped by channel coding, transport channel and physical channel, spread and modulated by physical channel, and then formed the data flows of radio interfaces to be transported on the radio interfaces. At the receiver side the reverse process will be applied.

2.7.2 Spreading Spectrum and Scrambling

On radio interfaces, after source coding and channel coding, the data flow continues to spread spectrum, scramble and modulate.

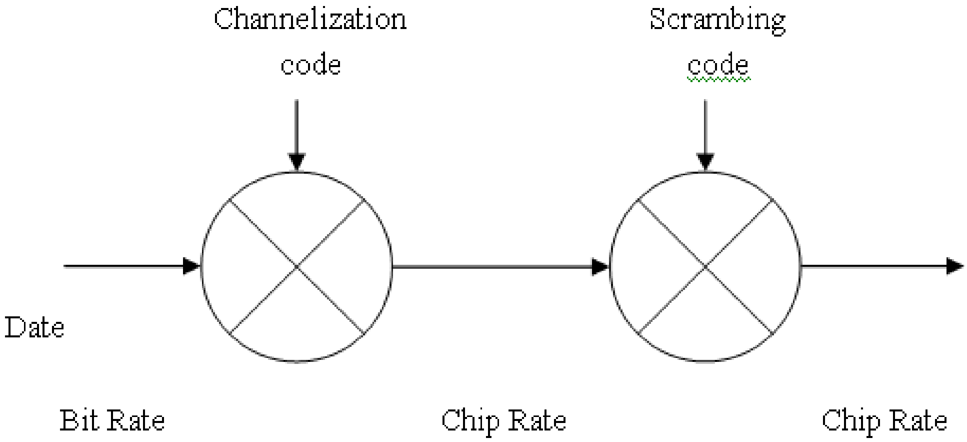

Figure 2. 8: Relation between Spreading Spectrum and Scrambling Code [20].

The code word used for spreading spectrum is called channelization code, for which Orthogonal Variable Spreading Factor (OVSF) code is used. The code word used for scrambling is called scramble, which adopts Gold sequence.

Spreading spectrum and channelization code

Channelization code is used to distinguish the transmission from the same source, that is, different physical channels of the same terminal between the downlink and upper-link connection of a sector. The spread spectrum/channelization of UTRAN is based on OVSF technology.

OVSF can change the spreading factor and keep the orthogonallity among different spreading codes with different lengths. If one connection uses variable spreading factors just select the channelization codes from the branch of the code tree directed by the minimum spreading factor code.

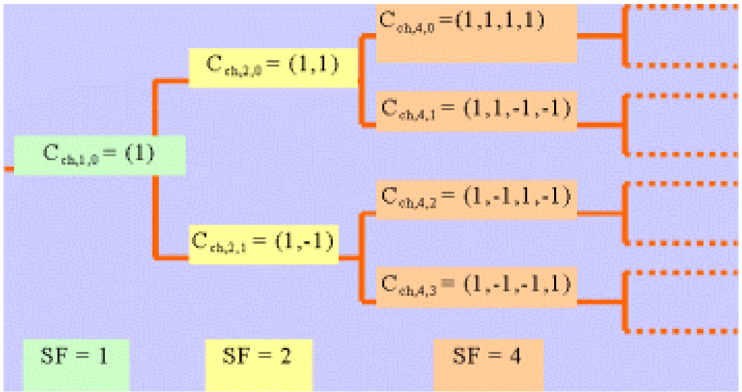

Figure 2. 9: Structure of channelization code tree [20].

Scramble

Scramble is used to separate the terminals or BSs, and it is used after spreading spectrum, so it does not change the bandwidth of signals but only separate the signals from different sources. After scrambling, the problem that several transmitters use the same code word spreading spectrum is solved.

2.7.3 Logical Channel

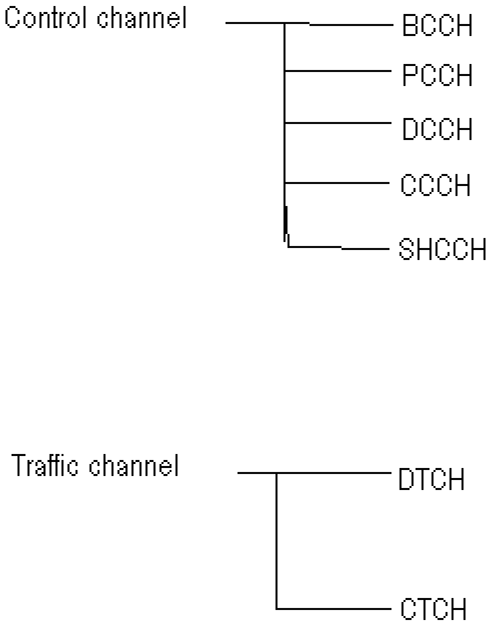

Figure 2. 10: Types of logical channels [20].

Control channel: The following control channels are only used to transmit the information of control plane. Broadcast Control Channel (BCCH): Downlink channel used to broadcast system messages. Paging Control Channel (PCCH): Downlink channel used to send paging messages. Common Control Channel (CCCH):

Bidirectional channel used to send control messages between the network and UE. Dedicated Control Channel (DCCH): it is a Bidirectional channel, which will be used to send and receive control messages between the network and UE.

Traffic channel: The following traffic channels are only used to transmit the information of user plane. Dedicated Traffic Channel (DTCH): Bidirectional point-to-point channel dedicated for one UE and used to transport user information [20].

Common Traffic Channel (CTCH): it is a Point-to-point down link channel which is used to transport the dedicated subscriber information for all or a group of UEs.

2.7.4 Transport Channel

Types of Transport Channels

A transport channel is used at the physical layer to provide services for the upper layer. It defines the mode and features of data transmission on air interfaces. It is divided into two types: Dedicated channel and common channel. The main difference between them is: Resources in the common channel are shared by all users or a group of users within a neighborhood, while resources in the dedicated channel are defined by the dedicated code on specific frequency, and they are used only for individual users. The figure in 2.11 shows the different transport channel types and their work flow direction as unilateral (single line) and bilateral direction (double line) [20].

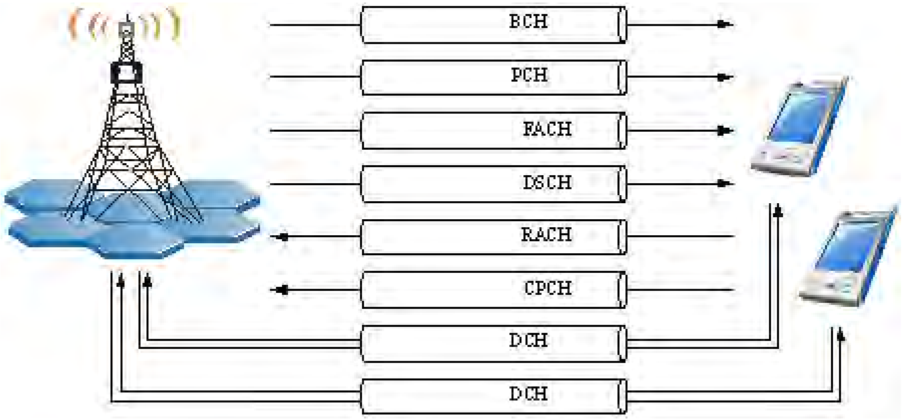

Figure 2. 11 Transport channels [22].

Dedicated Transport Channel

Only one kind of dedicated transport channel exists, that is, Dedicated Channel (DCH). The Dedicated Channel (DCH) is an uplink or downlink channel. In the whole or part of the neighborhood, DCH uses beam-forming antenna to transmit.

Common Transport Channel

Totally, there are the following six transport channels:

- Random Access Channel (RACH): it is an uplink transport channel. It always receives information in the whole cell. It features collision and adventure, using open loop power control.
- Broadcast Channel -BCH: The Broadcast Channel (BCH) is a downlink transport channel that is used to broadcast system- and cell-specific information. The BCH is always transmitted over the entire cell and has a single transport format.

- Forward Access Channel -FACH: The Forward Access Channel (FACH) is a downlink transport channel. The FACH is transmitted over the entire cell. It is used to transmit control information after Base station has received the random access requirement sent by UE. FACH is also can be used to send packet data.

There is one or several FACH within one cell. One of them must has low data rate so all terminals in this cell can receive it. The others can have high data rate.

- Paging Channel – PCH: The Paging Channel (PCH) is a downlink transport channel. The PCH is always transmitted over the entire cell. The transmission of the PCH is associated with the transmission of physical-layer generated Paging Indicators, to support efficient
- Common Packet Channel (CPCH): it is an uplink transport channel which is associated with the dedicated channel of a downlink. This dedicated channel is used to provide CPCH power control of the uplink and CPCH control commands [21].
- Downlink Shared Channel (DSCH): it is a downlink transport channel shared by some UEs, associating with one or more DCHs. In the whole or part of the cell, DSCH uses beam-forming antenna to transmit.

Mapping from the Logical Channel to the Transport Channel

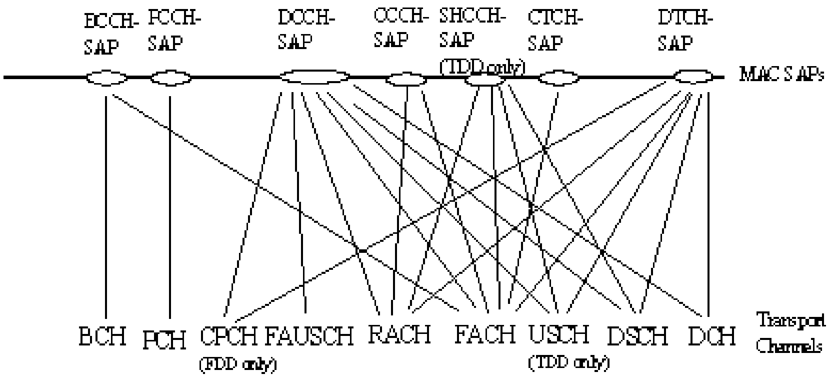

Figure 2. 12: Mapping between the logical channel and the transport channel [21].

In addition to the transport channels introduced earlier, there exist physical channels to carry only information relevant to physical layer procedures. The Synchronization Channel (SCH), the Common Pilot Channel (CPICH) and the Acquisition Indication Channel (AICH) are not directly visible to higher layers and are mandatory from the system function point of view, to be transmitted from every base station. The CPCH Status Indication Channel (CSICH) and the Collision Detection/Channel Assignment Indication Channel (CD/CA-ICH) are needed if CPCH is used [22].

2.8 Fundamentals of the UMTS Technology

2.3.1 Channel Coding/Decoding

A radio channel is an adverse transmission channel. When digital signals transmitted over a radio channel, bit errors may occur in the transmission data flow due to various reasons, causing image jumps and disconnection at the receive end. The step of channel coding can be used to process the data flow appropriately, so that the system can have error correction capability and anti-interference capability to certain extent, thus greatly avoiding bit errors in the code flow. Therefore, channel coding aims at increasing data transmission efficiency by reducing bit error rate [17].

Ultimately, channel coding intends to increase the reliability of the channel, but it may reduce the transmission of useful information data. Channel coding works by inserting some code elements, usually referred to as overhead, into the source data code flow, for error detection and correction at the receiving end. This is like the transport of glasses. To ensure that no glasses are broken during this process, we usually use foams or sponge to package them. However, such packaging reduces the total number of glasses. Similarly, over a channel with fixed bandwidth, the total transmission code rate is fixed. As channel coding increases data amount, the useful information code rate is reduced [21].

2.8.1 Principles of Interleaving/De-interleaving

Interleaving/de-interleaving is an important step of the combined channel error correction system. The actual errors in the channel are usually burst errors or both burst errors and random errors. If burst errors are first discretized into random errors, which are then corrected, the system's anti-interference performance can be improved. The interleaver works to discretize long burst errors or multiple burst errors into random errors, that is, discretizing the errors [18].

The interleaving technology rearranges the coded signals by following certain rules. After de-interleaving, burst errors are dispersed over time, making them similar to random errors that occur separately [17].

2.8.2 Spread Spectrum

Spread Spectrum is an information transmission mode. It modulates information signals with spreading code at sending end and enables spectrum width of information signals much wider than bandwidth for information transmission. It dispreads at receiving end with same spreading code, to resume data of transmitted information [18].

2.8.3 Modulation and Demodulation

Modulation is the process to use one signal (known as modulation signal) to control another signal of carrier (known as carrier signal), so that a characteristic parameter of the later changes with the former. At the receiving end, the process to restore the original signal from the modulated signal is called demodulation.

During signal modulation, a high-frequency sine signal is often used as the carrier signal. One sine signal involves three parameters: amplitude, frequency and phase. Modulation of each of these three parameters is respectively called amplitude modulation, frequency modulation, and phase modulation [19].

2.9 UMTS Advancements to HSPA+

2.9.1 WCDMA and HSPA evolution

Version	Released	Info Related to 3G and LTE

Version	**Released**	**Info Related to 3G and LTE**
Release 99	**2000 Q1**	first UMTS 3G networks, incorporating a CDMA air interface
Release 4	**2001 Q2**	Originally called the **Release 2000** - added features including an all-IP Core Network
Release 5	**2002 Q1**	Introduced IMS and HSDPA
Release 6	**2004 Q4**	Adds HSUPA, MBMS, enhancements to IMS.
Release 7	**2007 Q4**	This specification also focuses on HSPA+ (High Speed Packet Access Evolution).
Release 8	**2008 Q4**	First **LTE** release. All-IP Network (SAE). Dual-Cell HSDPA.
Release 9	**2009 Q4**	WiMAX and LTE/UMTS Interoperability. Dual-Cell HSDPA with MIMO, Dual-Cell HSUPA. LTE HeNB.
Release 10	**2011 Q1**	Backwards compatible with release 8 (LTE). Multi-Cell HSDPA (4 carriers).
Release 11	**2012 Q3**	Advanced IP Interconnection of Services.

Version	**Released**	**Info Related to 3G and LTE**
Release 12	**March 2015**	Enhanced Small Cells, Carrier Aggregation, MIMO (3D channel modeling, elevation beam forming, massive MIMO), New and Enhanced
Release 13	**March 2016**	LTE in unlicensed, LTE enhancements for Machine-Type Communication. Elevation beam forming / Full-Dimension MIMO, Indoor positioning

Table 2. 2: summary of different releases [13].

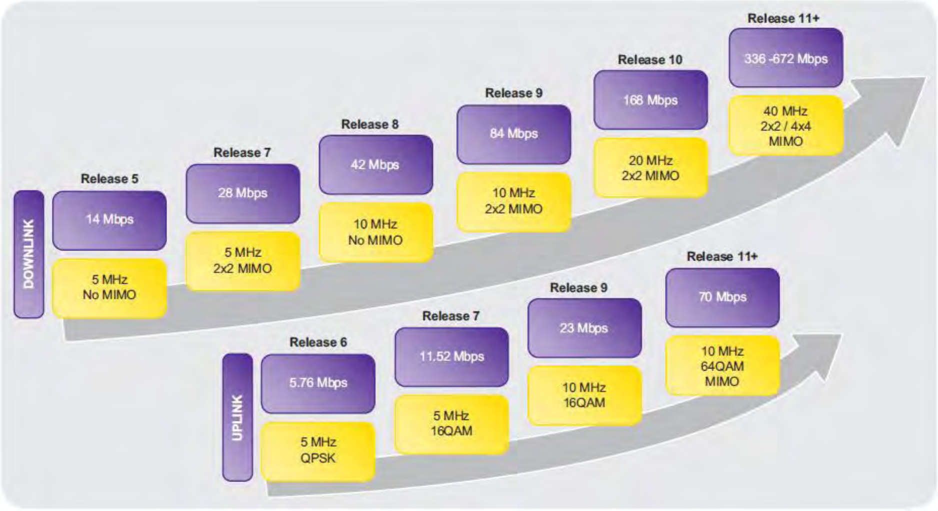

Figure 2. 13: WCDMA Evolutions to HSPA+ [13].

Figure 2.13 shows the different evolutionary releases of WCDMA and their corresponding capability and change compare to their previous versions.

2.10 HSDPA Common Carrier with R99

HSDPA can share a carrier frequency with R99. A cell can provide R99 services and HSDPA services at the same time, and public resources (including channelization codes, Node B transmit power, and Iub interface transmission bandwidth) of the cell can be allocated between R99 services and HSDPA services [32].

The sharing mode has the following advantages:

- The R99 CS/PS service shares frequency and power with the high-speed data service supported by HSDPA, thus utilizing system resources fully.
- Services can be selected flexibly, thus avoiding UE cell selection and camping caused by the independent carrier frequency.
- Alows fast and convenient upgrade, thus reducing investment

If an operator has limited frequency resources but has to provide the R99 services, the mode of sharing the carrier frequency allows the operator to provide high-speed data services through the residual resources of R99. However, the peak rate and throughput provided by the cell are reduced and the experience

2.11 HSDPA Dedicated Carrier

HSDPA can also use an independent carrier frequency. HSDPA uses a different carrier frequency from R99 for building a dedicated network layer. In addition to the independent carrier frequency of HSDPA, the carrier frequency of R99 should also be deployed so as to support the traditional CS service and low-speed PS service. The R99 network offers the solution to coverage and the high-speed PS service is carried over the HSDPA network first [22].

The independent carrier frequency mode has the following advantages: independent networking, simple planning, low adjacent-channel interference, and higher peak capacity. HSDPA needs to occupy a separate precious frequency and related resources, and incurs high expenses of network construction. In the initial phase of network operation, the independent carrier frequency mode may cause the low degree of sharing. Due to users' different service needs (CS or PS), inter-frequency handover can occur, thus affecting network reliability and user experience [34].

If the operator has more frequency resources than required by the R99 services, an independent carrier frequency can be deployed to provide the HSDPA services. As the spectrum utilization of the HS-DSCH is higher than that of the DCH, the independent carrier frequency provides the following benefits:

- Attain higher peak rate and cell throughput
- Improve the subscriber experience of the mobile data service
- Reduce the unit cost of the high-speed data service

In the initial phase of network construction, the independent carrier frequency mode is not recommended. However, the number of PS users increases while the network is developed to a certain phase or the application is an indoor network scenario. In this case, a separate frequency can be deployed to build a network that only supports the PS service [32].

2.12 WCDMA R99 Evolution to HSPA

WCDMA 3GPP Release 99 provides data rates of 384 Kbit/s for wide-area coverage. However, as the use of packet data services increases and new services are introduced, higher speed and greater capacity are required – at a lower production cost.

WCDMA 3GPP Release 5 extends the specification with High Speed Downlink Packet Access (HSDPA) which is a new downlink transport channel that enhances support for high-performance packet data applications. This significantly reduces latency and provides peak data rates of up to 14 Mbit/s. This enhancement is the first step in the evolution of WCDMA performance.

WCDMA 3GPP Release 6 introduces a new transport channel in the uplink. This Enhanced Uplink also known as High Speed Uplink Packet Access (HSUPA) provides higher throughputs, reduced latency and increased capacity. A peak data rate of up to 5.8 Mbit/s can be provided with Enhanced Uplink. Together HSDPA and Enhanced Uplink (HSUPA) are known as High Speed Packet Access (HSPA).

High Speed Packet Access (HSPA). HSPA improves the end-user experience by: increasing peak data rates to 14 Mbit/s in the downlink and 5.8 Mbit/s in the uplink.

HSPA Enhancements

HSPA is an enhancement of WCDMA (R99). HSDPA is based on 'fat-pipe', shared channel transmission. Its key features are:

- Shared channel and multi-code transmission
- Higher-order modulation

- Short Transmission Time Interval (TTI)
- Fast link adaptation
- Fast scheduling
- Fast hybrid Automatic Repeat Request (ARQ)

Introduced in WCDMA 3GPP Release 6, Enhanced Uplink adds a new transport channel to WCDMA called Enhanced Dedicated Channel (E-DCH). Enhanced Uplink improves uplink performance with reduced latency, increased data rates and increased capacity, making it a natural complement to HSDPA for high-performance packet data applications. In order to meet these targets, Enhanced Uplink supports several new features:

- Multi code transmission
- Short Transmission Time Interval
- Fast hybrid Automatic Repeat Request
- Fast scheduling

WCDMA uses power control to compensate for differences and variations in the Instantaneous radio channel conditions of the downlink. In principle, power control gives communication links with bad channel conditions a proportionally larger part of the total available cell power [23]. This ensures similar service quality to all Communication links, despite differences in radio channel conditions.

WCDMA 3GPP Release 99 uses Quadrature Phase Shift Keying (QPSK) modulation for downlink transmission. Besides QPSK, HSDPA can also use 16 Quadrature Amplitude Modulation (16QAM) to provide higher data rates [23]. Because 16QAM has twice the peak rate capability of QPSK, it makes more efficient use of bandwidth than QPSK. However, it also requires better radio channel conditions than QPSK. QPSK uses two bits per symbol and 16QAM uses four bits per symbol, as illustrated in Figure 2.14.

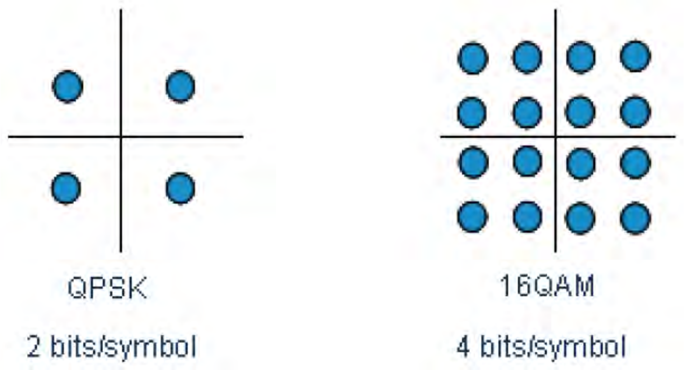

Figure 2. 14: HSPA and multi code transmission [13]

2.12.1 Modulation schemes used with HSDPA

WCDMA 3GPP Release 99 uses Quadrature Phase Shift Keying (QPSK) modulation for downlink transmission. Besides QPSK, HSDPA can also use 16 Quadrature Amplitude Modulation (16QAM) to provide higher data rates. Because 16QAM has twice the peak rate capability of QPSK, it makes more efficient use of bandwidth than QPSK. However, it also requires better radio channel conditions than QPSK. QPSK uses two bits per symbol and 16QAM uses four bits per symbol.

2.12.2 Evolving HSPA to HSPA+ through 3GPP Releases 7, 8 and 9

3GPP Release 7 with higher-order modulation (64 QAM) and support of multiple inputs, multiple output (MIMO) technology in the downlink, supports data rates of up to 28Mbps in the downlink and 11.5Mbps in the uplink, on top of this continuous packet connectivity (CPC) and enhanced CELL_FACH state, contributes on the improvement of capacity and battery times in user equipment (UE) [23].

3GPP Release 8 also had further improvements. In the downlink, using either a combination of MIMO and 64QAM or dual-cell HSDPA for operation on two 5MHz carriers with 64QAM, data rates reach up to 42Mbps. Additional Release 8 features include enhancements to the common states, and Integrated Mobile Broadcast (IMB), which gives existing [13].

3GPP Release 9 focuses on the support of features that further increase bit rates: more than 100Mbps using three to four 5MHz blocks of downlink spectrum, and 23Mbps using two 5MHz blocks of uplink spectrum [23].

HSDPA: Better Resource Mgmt. and Throughput

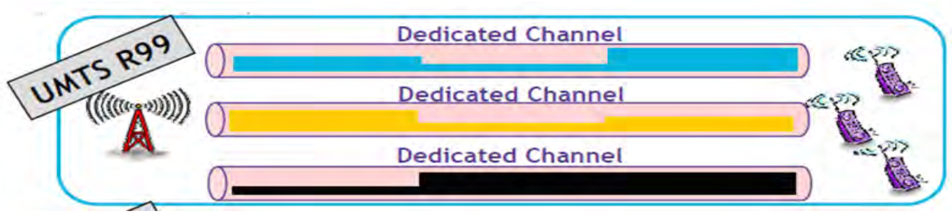

Figure 2. 15: UMTS R99 dedicated channel [13]

Figure 2.15 shows that the Radio Bearer resource is assigned as a dedicated channel for each user. The Radio Bearer is attributed to other users and doesn't change even if the customer throughput requirement is fluctuating. The Radio Bearer can only be downgraded if the radio condition degrades or if the requirement decreases (SLOW, second order) the Modulation is fixed (QPSK) [13].

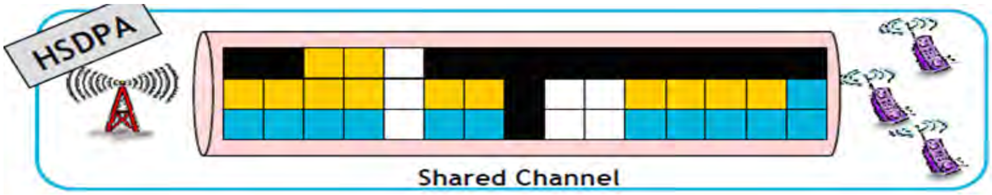

Figure 2. 16: HSDPA shared channel [13]

Unlike figure 2:15 Figure 2.16 shows that in HSDPA technology only one type of Radio Bearer is used with one Spreading Factor. The resulting channel is shared with all the customers based on their radio condition and their throughput requirement each 2ms (FAST management), the resource is used fully [13]. The throughput is based on the link adaptation managed by radio condition (CQI), changed each 2ms (FAST). The link adaptation is done by changing the Modulation (QPSK,16&64 QAM) and the coding scheme [13].

By learning the system structure, interface technology, it evolution and advancements, protocol structure and the process of physical channels and layers, we can deeply understand the operating principle of WCDMA, and get known to the WCDMA network planning very easily.

Chapter 3 UMTS Radio Network Planning

With the emergence of 3G mobile communication technology, the construction of the UMTS network will bring a profound evolution, which makes higher requirements for network planning. At present, users are greatly interested in this kind of technologies. This mobile communication technology is different from the traditional GSM network planning in terms of essence.

GSM network planning

The GSM network planning is based on radio wave propagation analysis. According to the transmitting power and antenna configuration of BTS, its coverage area is calculated [2]. Normally, only the downlink coverage area is calculated, so the GSM technology does not take uplink coverage area into consideration. The next step is performed by network planning engineers to analyze the required cell capacity. According to the calculated cell area, the traffic of cells can be estimated with the help of electronic map, and then the required channel numbers are calculated through traffic models (such as Erlang-B or Erlang-C). Next, it is the frequency distribution for BTSs, and the same frequency can only be reused among enough-distanced cells, to avoid interference [2].

To expand the network in the future, the network planning engineer just needs to distribute new channels to the corresponding cells. As long as there is appropriate frequency in the overall frequency planning and the expansion does not exceed the maximum capacity of the BTS, the network does not require other adjustments. Otherwise, new BTSs or sectors should be added, and new frequency calculation and channel distribution are required.

- UMTS network planning

Compared with the GSM network planning, the UMTS network planning features the following differences:

Cell breathing: The CDMA network is totally different from the GSM network. Since channels and users are not separated for consideration, there is tight relation between coverage and capacity. The cell with more traffic has less coverage area. In the CDMA network, more traffic means more interference [24]. This kind of effect of dynamic change of cell area is called as “cell breathing”. This can be illustrated through the following visual example. In a birthday party of a friend, many guests come, more people taking will cause it is harder to hear the voice of opposite party clearly [2]. If in the beginning, you can talk with a friend at another end of the room, you cannot hear what he is saying at all when the room is very noisy [25]. It indicates that the “cell radius” of talking area is shortened. The UMTS network planning engineer faces a network changing dynamically.

In UMTS network planning, the network expandability should be taken into consideration. The network planning engineer cannot simply add frequency to the related cell as planning GSM network. In the beginning of network planning, a determined traffic signal redundancy should be taken into consideration, and this redundancy will be used as “compensation” to the interference caused by increased traffic [24]. This shows that, from the very beginning, it is required to construct the network with smaller cells or more NodeBs, resulting in higher investment cost. If the traffic signal surplus is too small, there is only one way: adding Node B's when expanding [2].

The network planning engineer should notice the above issues, because enhancing transmitting power simply cannot reduce the receiving signal deterioration caused by an increase in traffic [2]. Enhancing transmitting power can only improve the receiving signal of a cell but will add interference to the adjacent cells. As a result, the whole network communication quality will be influenced.

The enhanced transmitting power raises the valid range of cell, but to satisfy the requirements of remote mobile subscribers, it is necessary to enhance transmitting power by multiple times, which will influence the talking quality of other mobile subscribers[25]. Let's return to the above party example. You can enhance your voice to continue the conversation with the friend at another end of the room, but at the same time, other guests also raise voice to talk with others [2]. As a result, the whole room is submerged in noise.

The corresponding relationship between transmitting power and cell capacity is gradual. Since the UMTS cell load is subject to saturate, the UMTS network planning engineer must reduce the full-load ratio [26]. The detailed parameters depend on different services and how much the network carrier would like to risk. Here, the "cell breathing" effect is used. The adjacent cells can mutually compensate load, called as soft load [2]. Due to cost, the network capacity cannot be increased on a large scale.

Near-far effect:

Another typical issue of the CDMA network is near-far effect. Since all the subscribers in the same cell share the same frequency, it is important that each subscriber in the whole system transmits signal at the minimum power. Let's return to the above party example. If someone is shouting in the room, the conversation among all the other guests will be influenced [27]. In the CDMA network, this problem can be solved through power control.

Power control mechanism has been implemented in the UMTS hardware. But the network planning engineer will face the other case of this problem. When a subscriber is far away from the Node B, he needs a majority of transmitting power, resulting in power shortage for other subscribers. This means that the cell capacity is related to the actual subscriber geographical distribution. When subscriber density is rather large, statistics average value can be used to solve this problem. When subscriber quantity is small, it is necessary to perform dynamic analysis to the network through simulations [2].

Uplink and downlink:

The UMTS network traffic is asymmetrical, that is, the data transmission quantity in the network uplink differs from that in downlink. The network planning engineer should calculate values in two directions and then combine them together properly. In this way, the network planning work will be very complicated. Uplink is a typical limit factor for the valid coverage range of UMTS cell, or we can say that uplink is coverage-limited and downlink is capacity-limited. The transmitting power in uplink is provided by UE and the one in downlink is provided by Node B [2].

Other differences:

Compared with GSM network, the UMTS network features other differences. The GSM network solves capacity problem with sector partition method. The cell with too much traffic is divided into multiple sectors, and antennas are added correspondingly. This method is also used for the UMTS network, but its effect is not enough. The change of cell coverage will cause the near-far effect mentioned above, and overlapped sectors will interfere mutually because they use the same frequency [2].

The declination angle (mechanical or electronic) of antenna plays an important role in the UMTS network. It can reduce the interference among adjacent cells and raise cell capacity implicitly. In the actual application, large declination angle can be chosen to solve this problem.

Compared with 2G traditional GSM network, the UMTS network features many differences. Especially, the UMTS network can run asynchronously, which causes "non-orthogonally" of transmission channel [18]. Let's return to the party example again. Even if the perfect planning can be made theoretically, that is, planning the person to talk in the certain time, it is impossible to reach that ideal goal factually, because the watches of all the guests cannot be synchronous exactly [2].

Through the above analysis, we can clearly see that the UMTS network planning needs more cost, compared with the GSM mobile communication network planning. The UMTS network planning is rather complicated, because many system parameters are closely related to each other and should be calculated at the same time [2].

3.1 UMTS Network Planning Procedure

Compared with the second generation mobile communication, it is difficult to forecast different service models in the third generation system network owing to introduction of several kinds of high bit rate services. As for radio network planning, in any case, it is required to calculate the link budget, capacity and number of NodeBs, estimate the coverage of base station and input design parameters. In addition, it is required to design the whole network, calculate the number of channel units, capacity of transmission lines, RNCs, MSCs and other units in a base station [2].

In network planning, performance measurements such as dropped call rate and Grade of Service (GOS) should be introduced to measure the network performance. High-bit rate services are provided at the cell area where base stations are covered equably, while low-bit rate services are provided to the edge of cell. The coverage can be designed as continuous coverage or hotspot coverage. Coverage of base stations should be estimated carefully according to different services and different implemented policies [2].

3.1.1 Pre-Planning of UMTS Network design

Getting the required information for a network plan is the most crucial part in building a cost effective quality network, a lot of different information are needed for initial network roll-out plan. Some of them are listed below.

- **Operators traffic usage**

This is the section where we can identify what kind of services are planned and how these services will be implemented, the table below shows sample business plan [28].

Traffic Usage in GB/Month/User		
HSPA+		
	Dongle	Smart phone
Traffic per user per month in GB	10	1
% of daily traffic at busy hour is 10%		
downlink ratio is 70%		
Active user is assumed to be 70%		

Table 3. 1: input traffic usage and service type from Ethiotelecom [29].

- **Technical Sections of business plan**

This section contains the desired coverage, capacity, quality, features, service mix and customer intake plans [28]. In addition to the above table, some of the technical items are listed in the table below; these kinds of parameters are provided by operator during request for proposal time (RFP).

UMTS Link Budget Based on RSCP						
Morphology	Dense Urban		Urban		Suburb	
UL/DL	UL	DL	UL	DL	UL	DL
Frequency (MHz)	1950	2140	1950	2140	1950	2140
Target load	50%	75%	50%	75%	50%	75%
Softer HO Gain(TCH)	3		3		3	
Area Coverage	95.00%		95.00%		95.00%	
Outdoor RSCP	-80		-85		-90	
Propagation Model	Cost231-Hata		Cost231-Hata		Cost231-Hata	

Table 3. 2Technical input parameters.

- **Operators risk analysis documents**

This section will identify where bottlenecks will be and show the critical path of the project. Most of the time site acquisition work is in the critical path, which means that site RF planning will be impacted [28].

- **Operator's internal studies of mobile usage**

Information on mobile usage for different areas is very helpful and can pinpoint where 3G customers and key corporate clients are likely to be. Mobile usage profiles and customer distribution information is required to simulate the network load [28]. In the forecast process inputs like number of population, house hold, housing centers like condominium and real state houses, Education centers like primary ,secondary and

higher education centers, business centers like small and medium , big business areas, enterprises, entertainment areas ,health centers like clinics and hospitals and others like banks , government offices airports and NGO'S will be used as an input in the forecast process.

Sub City	Forecasted 3G Subscribers from 2010-2015G.c)
Bole	238,566
Kirkos	181,193
Yeka	171,301
Arada	146,734
Nefas Silk Lafto	170,164
Kolfe Keraniyo	129,445
Addis Ketema	117,154
Akaki Kality	130,253
Gulele	113,489
Lideta	101,701
Total	1,500,000

Table 3. 3: UMTS forecasted subscriber by sub city from Ethiotelecom [29].

- **Government Statistics**

Government sources can provide statistics of population type and information such as income, distribution of wealth, taxation, and spending habits etc., which are useful to forecast future mobile usage in different areas [29].Most of the time all of this information is compressed into the operators request for quote. This typically calls for an estimation of how many base station locations each network vendor thinks is required to provide a network [28]. The operator normally asks vendors to guarantee the level of coverage for a certain load level, using the minimum amount of base stations and cost [28].

The most crucial parameters for the initial roll-out are:

Capacity requirements - the forecasted customers and service usage in each area of the network (with BTS site capacity calculation) should be known in order to get the required amount of base stations for capacity [28].

Coverage requirements - the **link budget** of high data rate services should be calculated in order to estimate the required base station amount in each network area to get the amount of base stations to cover the required area [28].

Dense Urban:	-80 dBm for 95% of cases
Urban:	-85 dBm for 95% of cases
Sub Urban:	-90 dBm for 95% of cases

Table 3. 4: Coverage requirement based on signal strength.

3.2 UMTS Coverage Planning

This section talks about Coverage planning methods, inputs parameters, assumptions and design principles. The purpose of coverage planning is to ensure the availability of the service signal in the entire service area. The coverage can be designed as continuous coverage or hotspot coverage. During the process of planning, you can continually take an analysis to the network and evaluate the interference ratio to estimate the coverage in different cells. Such iterative process may be repeated until the convergence of coverage is achieved. Design tools can be adopted to realize the process automation and in the meantime detect leaks in the coverage [2].

3.3 Morphology Classification

In this thesis three types of morphologies are assumed: Dense Urban, urban and Suburban. The table below describes the criteria's behind each morphology classification.

Scenario	Scenario Description
Dense Urban	Buildings are densely distributed and average building height is in >=15m.
	Subscriber density is very high
	Traffic-intensive
	High service rate requirement
	Key area of data service development
Urban	Average building height is around 10-15m.
	There are some open area and green lands in this scenario.
	High traffic; medium service rate; common data service demands.
Suburban	Average building height is around 5m~10m. Buildings are sparsely distributed.
	There are many open, vegetation and green lands in this scenario
	Low traffic; low-speed or no data service

Table 3. 5: Classification criteria [29]

3.4 Input signal strength requirement.

It is possible to make the same signal strength requirement value for DU, U and SU, but each area have different value of indoor penetration/building penetration loss, fading value and even diffraction, reflection, refraction and scattering value. That is why different morphological areas have different value of signal strength requirement. Generally the losses experienced in dense urban is greater than urban and in urban is greater than Sub urban. So in order to reflect these differences, different areas have different requirement of received signal strength value.

Dense Urban(DU):	-80 dBm
Urban(U):	-85 dBm
Sub Urban(SU):	-90 dBm

Table 3. 6: Input coverage signal strength requirement.

3.5 Link Budget and coverage.

The WCDMA link budget calculations start from the uplink direction, because Uplink interference is usually the limiting factor in CDMA systems. The starting point of a link budget calculation is to define the required data rate(s) in each network areas and Eb/No targets [30].

The next step is to gather data like a BTS output power, receiver noise figure, antenna types, usage of intelligent antenna systems in specific areas, possible additional line amplifiers and used diversities from vendor and information's like data services, system loading factor, estimated mobile speeds, penetration losses, coverage reliability and a used fade margin from the operator[30]. And finally mobile power levels, the chip rate and the process gains will be collected from standards, by putting all these information's in to the link budget and using appropriate propagation model we will get a cell range and from that cell coverage area will be calculated [30].

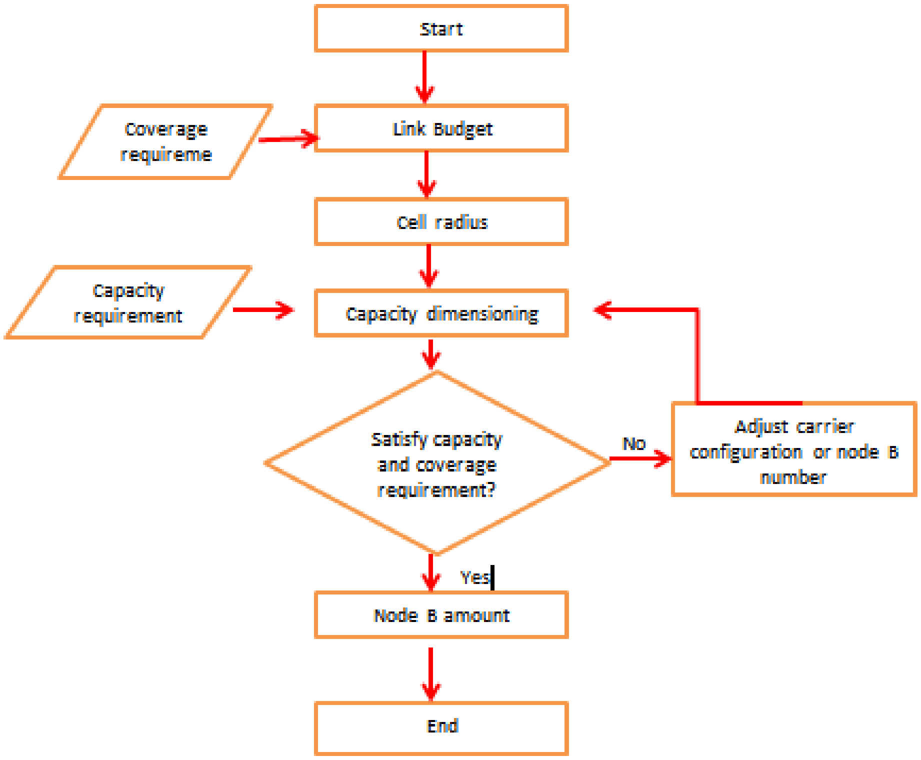

Figure 3. 1: Planning procedure [31].

Step1. Link budget is performed to get the cell radius and the distance between sites.

Step2. Output the site layout based on link budget.

Step3. Output the sites number based on coverage simulation.

Step4. Distribute the forecasted subscribers to different Woredas.

Step5. Utilize the provided traffic model, get the total capacity.

Step6. Configuration dimensioning for each site based on capacity and numbers of sites, considering different configuration for different scenarios.

The table below shows the different parameters and their corresponding values considered in the link budget.

The calculation formula of uplink link budget is as follows:

The maximum allowed space path loss = mobile station transmitting power (dBm) + mobile station antenna gain (dB) − human body loss (dB) − BS feeder loss (dB) + BS receiving antenna gain (dBi) + soft handoff gain (dB) − building or car body penetration loss (dB) − slow fading margin (dB) − power control margin (dB) − interference margin (dB) − BS receiving sensitivity (dBm).

	dense urban				urban		sub urban	
	unit	Formula	down link	uplink	down link	uplink	down link	uplink
Target load	%	A	0.75	0.5	0.75	0.5	0.75	0.5
Transmitter characteristics								

	dense urban				urban		sub urban	
	unit	Formula	down link	uplink	down link	uplink	down link	uplink
Transmitter power	dbm	B	43	21	43	21	43	21
Transmitter antenna gain	dbi	C	18	0	18	0	18	0
Tx cable loss	db	D	0.5	0	0.5	0	0.5	0
Tx body loss	db	E	0	0	0	0	0	0
Transmitter EIRP(including losses)	dbm	F=B+C+D+E	60.5	21	60.5	21	60.5	21
Receiver characteristics								
Receiver antenna gain	dbi	G	0	18	0	18	0	18
Thermal noise density	dbm/hz	H	-174	-174	-174	-174	-174	-174
Receiver noise figure	db	I	8	5	8	5	8	5
Receiver noise density	dbm/hz	J=H+I	-166	-169	-166	-169	-166	-169
Receiver noise power	dbm	K=J+10*LOG10(3840000)	-100.157	-103.1566878	-100.1566878	-103.1566878	-100.1566878	-103.1566878
processing gain	db	L=10*LOG10(3840/64)	17.78151	17.7815125	17.7815125	17.7815125	17.7815125	17.7815125
Interference margin	db	N=-10*LOG10(1-A)	6.0206	3.010299957	6.020599913	3.010299957	6.020599913	3.010299957
receiver sensitivity	dbm	O	-105	-120	-105	-120	-105	-120
RX cable loss	db	P	0	0.5	0	0.5	0	0.5
RX body loss	db	Q	0.5	0	0.5	0	0.5	0
Diversity gain	db	R	0	0	0	0	0	0
Fast fading marigin (power control headroom)	db	S	0	4	0	4	0	4

	unit	Formula	dense urban down link	dense urban uplink	urban down link	urban uplink	sub urban down link	sub urban uplink
Soft handover gain	db	T	3	3	3	3	3	3
Coverage requirement (outdoor)	%		95%	95%	95%	95%	95%	95%
Slow fading standard deviation	db	V	10	10	8	8	6	6
Slow fading margin	db	W	9.5	9.5	7.6	7.6	6.6	6.6
Building penetration loss	db	X	22	22	18	18	15	15
Allowed propagation loss	db	Y=F+G-O+R-S+T-W-X-Q+P	137	126	142.9	131.9	146.9	135.9
Cost 231 model								
Carrier frequency	MHz		2140	1950	2140	1950	2140	1950
BS antenna height	m	φ	20	20	25	25	30	30
MS antenna height	m	ϒ	1.5	1.5	1.5	1.5	1.5	1.5
Parameter A		α	46.3	46.3	46.3	46.3	46.3	46.3
Parameter B		β	33.9	33.9	33.9	33.9	33.9	33.9
Parameter C		θ	44.9	44.9	44.9	44.9	44.9	44.9
MS antenna gain function (large city)		M=3.2*(LOG10(11.75*ϒ))^2-4.97	-0.00092	-0.000919047	-0.000919047	-0.000919047	0.048999737	0.048999737
Path loss exponent		U=(θ-6.55*LOG10(φ))/10	3.637825	3.637825353	3.574349294	3.574349294	3.522485578	3.522485578
Path loss constant	db	Z=α+β*LOG10(1800)-13.82*LOG10(φ)-M	138.6744	138.6744224	137.3351261	137.3351261	136.1909224	136.1909224
Downlink	km	R1=10^((Y	0.89943		1.431163		2.01381	

	dense urban				urban		sub urban	
	unit	Formula	down link	uplink	down link	uplink	down link	uplink
range		-Z)/(10*U))	9		157		9212	
Uplink range	km	R2=10^((Y-Z)/(10*U))	0.448325		0.704597057		0.98116261	
Cell range	km	R=MIN(R1,R2)	0.448325		0.704597057		0.98116261	
Area of a cell	km2		0.391942		0.968091175		1.87722613	
Area of each section	km2		24.63		15.89		24.79	
Total cell			63		17		14	

Table 3. 7: Calculated link budget

From the above link budget result, the number of base station required to cover the dense urban, urban and sub urban area is 63, 17 and 14 respectively. A total of 94 node B's s are required to satisfy the coverage requirement of the whole sub city. Note that this is only the coverage result; it doesn't include the capacity requirement. In order to finalize the final site or cell quantity we need to calculate the capacity planning which will be covered in the next chapter.

Chapter 4 UMTS Capacity Planning

The capacity estimation is another important part of the scale estimation. The purpose of capacity estimation is to estimate the approximate BS number needed by the capacity according to the service model and service traffic demand of the network planning. Similar with the link budget, the capacity estimation should be performed from the uplink and downlink. For the UMTS system capacity, the interference is limited in the uplink direction and the BS power is limited in the downlink direction. In the 2 G CDMA network, the voice service is the main application service with symmetrical uplink and downlink traffic, the capacity is limited in the uplink direction, so the uplink capacity calculation is focused on in capacity estimation. However, in the UMTS network, the data service proportion is obviously increased and the network uplink and downlink traffic becomes asymmetric generally, and even the downlink capacity may be limited. Therefore, the UMTS capacity estimation should be performed from the uplink and downlink respectively.

The following steps are involved in capacity estimation:

- Hybrid service intensity analysis. The UMTS system can provide multiple services. The hybrid service intensity analysis makes the system capacity consumed by various services equivalent to that consumed by a single service.
- Uplink capacity estimation. Estimate the BS number that meets the service demand based on the hybrid service intensity analysis.

- Downlink capacity estimation. It is a verification process. The BS transmission power formula is used to calculate the channel number that can be provided by the current BS scale so as to verify whether this channel number

The number of installed transceivers limits the mobile network theoretical capacity, Interference, quality and grade of service will determine the system capacity [3]. The link budget is used to calculate the maximum allowed path loss and the maximum range for a cell. The link budget includes the interference margin, which is the increased noise level caused by greater load in a cell; so by increasing the cell load, cell coverage area becomes smaller, that's how cell coverage and capacity dimensioning are interlinked [32].

The first thing is to estimate a single transceiver and site capacity, the second part of the process is to estimate how many mobile users each cell can serve [2]. Once the cell capacity and subscriber traffic profiles are known, network area base station requirements can be calculated, estimations can be done in kilobits per subscriber [53].A lot of data is required for comprehensive network dimensioning; number of subscribers and growth estimations, traffic / user / busy hour / geographic segment and required throughput including service mixes in geographic segments for example [33].

4.1 Common Design Guidelines

After calculating the coverage and capacity requirements in each geographical area, the greater one of those two values has to be chosen, to optimize the used resources some readjustments should be made [28]. If a geographical area is coverage limited, the load on each sector can be reduced until coverage and capacity requirements match.

Reducing the load will cut the link budget interference margin and increase Node B count. If area is capacity limited, transmitter diversity can be added or amount of transceivers can be increased [28].

Operators are normally forced to co-locate their 3G base stations with existing sites or select new site locations only on buildings known to be owned by friendly site owners [28]. This limits the cell planning options and may sacrifice the network quality, but it helps to build networks faster. Forced co-location should be taken in to account in initial capacity and coverage planning, all variation to standard configuration may need pilot power, handover, antenna, and cable and base station power level modifications [28].

Some network areas need special attention very dense urban area, open spaces, in-building areas, water surroundings, hot spots and other special coverage areas need well planned approach. Out-of-Cell Interference versus soft-handover cell overlap has also to be considered. Hierarchical systems work with multi-frequency networks, but not with single-frequency systems (like CDMA). If multi-layered is planned, separate frequencies are needed for different layers [28].

There is no need to plan channelization codes as those are managed by the RNC. Unlike the channelization codes, the scrambling codes need to be planned. The uplink scrambling code for each user is allocated by the RNC, every RNC has a pool of codes that are unique to it [28]. Allocation of uplink scrambling codes to RNCs is a simple task, due to the huge number of available codes [28].Downlink scrambling codes planning is an important issue, which needs code planning to avoid interference.

4.2 UMTS capacity planning procedure

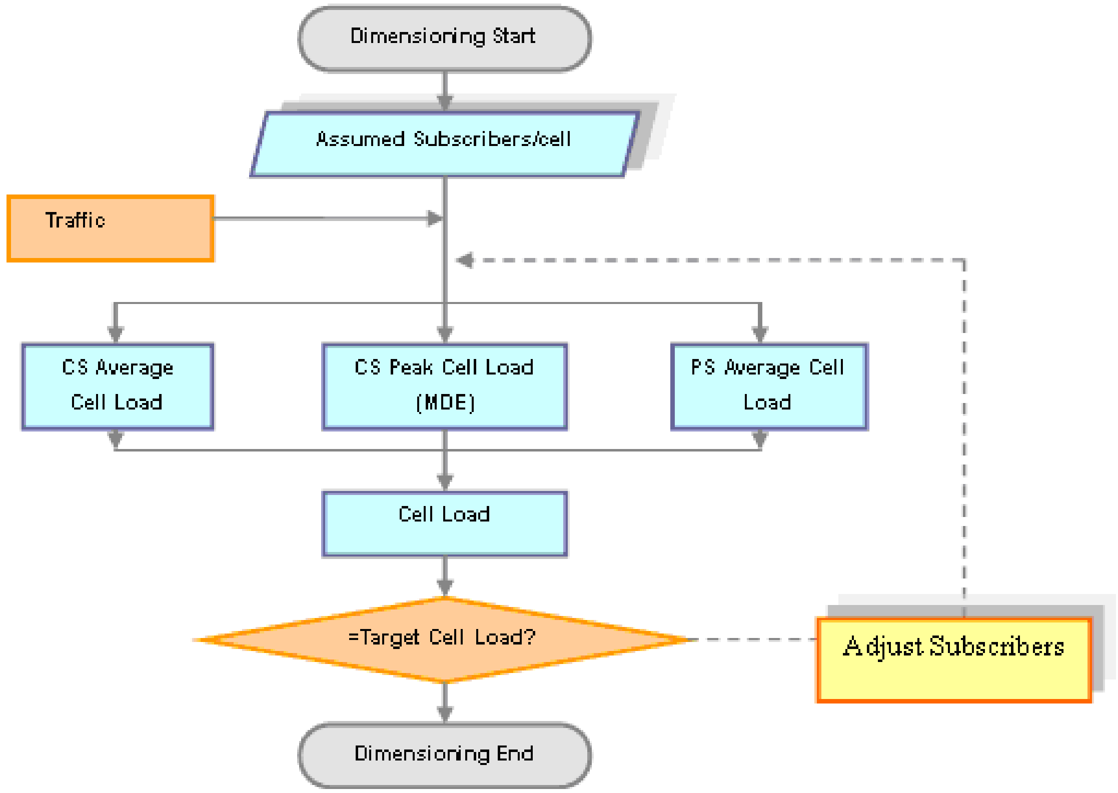

Figure 4. 1: UMTS Capacity Dimension Procedure [29].

The aim of UMTS capacity dimensioning is to obtain the number of subscribers supported per cell based on the traffic model, coverage. According to the traffic model mentioned in this planning, load per connection for different service can be calculated. According to load per connection for different service and cell load, the subscribers per cell per different service can be obtained and finally get the minimum one of different service subscribers per cell. Finally, the largest one among coverage and capacity result will be the final value. The detail of some key steps in capacity dimensioning will be introduced in the following section.

4.3 UMTS Traffic Model

Considered traffic model:

Traffic Usage in GB/Month/User	HSPA+		Voice
	Dongle	Smart Phone	SP
Distribution percentage	35% of subscribers	65% of subscribers	
traffic per user per month in GB	10	1	0.020 erl for major cities

Table 4. 1 input UMTS Traffic Model from Ethiotelecom [29].

- % of daily traffic at busy hour is 7% and down link ratio 70%
- Active users is assumed to be 70%
- This traffic per user includes normal traffic, signaling traffic and additional soft handover traffic, SP voice excludes additional soft handover traffic.

This traffic model is an input from operator for each user data consumption. According to current EthioTelecom sells model as shown in the figure below the provided traffic model is an economical and acceptable traffic model

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2ጊጋ ባይት	350 ብር
4ጊጋ ባይት	600 ብር
8ጊጋ ባይት	1000 ብር
10ጊጋ ባይት	1200 ብር
20ጊጋ ባይት	2200 ብር
30ጊጋ ባይት	3000 ብር

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Figure 4. 2: EthioTelecom sells model [34].

Taking the operator traffic Model as an input, the capacity calculation is done as follows:

- Step1: Data volume per month per user calculation

10GB*35%+1GB*65% =4.15GB (4.1)

- Step2: HSPA throughput per user calculation

Per day per user: “Step1” *8*1024*1024/30/3600 =322.34Kbps (4.2)

Busy hour is 10%;

Busy hour per user =322.34*10% =32.237Kbps (4.3)

- Step3: Busy hour per active user calculation

Active user ratio is assumed to be 70%;

Busy hour per active user 32.237*70%=22.5659Kbps (4.4)

- Step4: Convert voice traffic into data volume

  Voice unit is in Erlang, first it should be converted to kbps, then calculate the total supported throughput, the calculation is show as below:

Volume per user@Busy hour = ErlangPerUser@BH*3600*Activity Factor*Ri (4.5)

- AMR12.2, Activity Factor: 0.67
- Video Phone, CS 64, Activity Factor: 1
- PS services, Activity Factor: 0.9
- Ri: Bearer or Services bit rate, for example: AMR12.2 is 12.2kbps, CS64 is 64kbps

So, VolumeperUser @ BusyHour = 0.02*3600*0.67*12.2=588.5Kbits, convert it to kpbs: (4.6)

588.5/3600=0.16kpbs

- Step5:HSDPA and HSUPA throughput per user calculation

Down link ratio is 70%;

HSDPA throughput per user="step3"*70%+"step4"=22.5659*0.7+.16=15.95613 (4.7)

HSUPA throughput per user="step3"*30%+"step4"=22.5659*0.3+.16=6.92977 (4.8)

Unit: Kbps.

- Step6: HSDPA and HSUPA user per carrier calculation.

Method to estimate radio capacity of one cell:

One quick method to estimate capacity of one HSDPA cell is to get counters or composition of counters from Operation Maintenance Center (OMC).For one cell, you should retrieve for EACH HOUR over 1 WEEK with the following KPIs:

- Average TTI Utilization Ratio [%] (Percentage of occupied TTI over the hour).
- Average Cell Throughput [Mbps] (Total HSDPA Traffic Volume per hour).

By drawing a scatter chart with these data, a trend should be noticed. The maximum capacity is then the extrapolated Cell Throughput when load is at 100%.

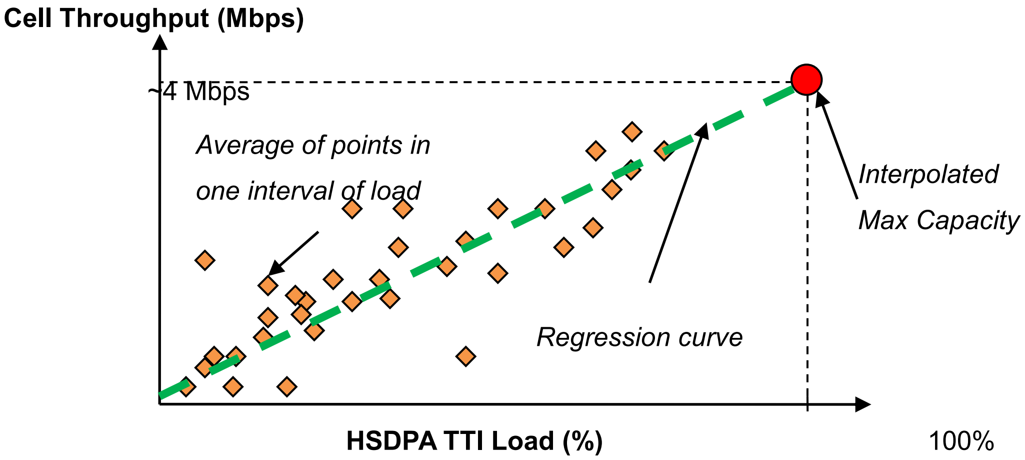


Figure 4. 3: Example of Throughput trend and radio cell capacity from orange lab [13].

The obtained value is the absolute maximum capacity. At this point, there is no guaranteed QoS to the users, so when doing dimensioning, a security margin should be taken 20% margin is recommended to avoid quality issues like congestion [23].

This radio capacity is fluctuating according to the cell and the interference level but it is often around 3 or 4 Mbps. It is worth noting that these values are far lower than the marketing throughputs (e.g. 21 Mbps for cat14 devices).it does not mean that instantaneous peak cell throughput could not be higher during quiet period, but during busy period, the average traffic intensity over the hour will be around 4 Mbps.

According to orange telecom laboratory test, the HSDPA average throughput per cell is 3.6Mbps, and HSUPA average throughput per cell is 1.9Mbps [13].

HSDPA user per carrier =3.6*1024/”step5” =3.6*1024/**15.95613**=232 users; (4.9)

HSUPA user per carrier =1.9*1024/"step5" =1.9*1024/**6.92977** =281 users. (4.10)

Hence the minimum value which is 232 subscribers per cell will be taken as the final result of subscriber capacity result per cell.

UMTS Cell Load Dimension Result

Bear	Cell Load	Traffic per subs	Active Subs/Cell
HSDPA+Voice	3.6 Mbps	15.95613 Kbps	232
HSUPA+Voice	1.9 Mbps	6.92977 Kbps	281

Table 4. 2: Configuration Dimension result.

Region	5 year forecasted UMTS subscriber value from Ethiotelecom for Bole sub city
Bole	**238,566**

Table 4. 3: UMTS Forecast Subscribers for Bole sub city from Ethiotelecom [29].

Base stations can be configured based on subscriber density and growth rate information's in each woreda of the sub city. Considering three sector cell the final carrier number can be calculated by dividing the forecasted subscriber quantity to the subscriber per cell/carrier. The final carrier result and site configuration is summarized in table 4.5

	UMTS Final Configuration	2100M Node B Number	2100M Carrier Number(Cell)
Bole Sub city	U111	9	30
	U222	6	36
	U333	22	198
	U444	64	768
Total		101	1032

Table 4. 4: UMTS Configuration Result.

4.4 UMTS Network Planning Output

So far the coverage and capacity are designed as per the requirement; the remaining work is to satisfy the signal strength requirement for each section of the area. Initially signal strength requirement measurement activity has to be done by selecting the high value of node B's among coverage and capacity dimensioning results in the network simulator tool. If the prediction result isn't as per the requirement the next step is to perform optimization activities like BTS re-positioning, mechanical and technical tilting modification. After performing these activities if the required signal strength wasn't achieved as per required the next and final step is to add additional nodes in the network. Therefore additional 4 node B's were added to meet the signal strength requirement on top of the final node B amount from capacity dimensioning (101 node B). Hence the final node B amount which can satisfy coverage, capacity and signal strength requirement becomes 105 nodes B.

Bole Sub City	Area (km2)	Final # Node B
Dense urban	24.63	68
Urban	15.89	22
Sub Urban	24.79	15
Total	62.31	105

Table 4. 5: Final node B result based on coverage dimensioning.

Chapter 5 Capacity Upgrade parameters

The objective of this chapter is to define the main notions relative to performance of UMTS radio access network, quality of service and capacity dimensioning.

5.1 Influence of radio conditions on user throughput

A specific characteristic of the radio interface is the heterogeneity of radio conditions over a cell. Consider for instance two users in a cell, one close to the base station and the other far from it. They will have different bit rates because they have different SINRs or CQIs) and thus profit from the allocated resources in a different manner [13].

Figure 5. 1: UE locations relative to Node B[13].

This heterogeneity of throughput is not only due to the distance to the base station but also to the environment notably indoor or outdoor and to the presence of obstructions between the users and the serving cell and neighboring cell also for the interferences

[32]. In this representation, users situated at cell edge will have lower throughputs than others at cell center.

Here is an example of curve giving the throughput as a function of distance to the base station for a user alone in the cell. This curve, based on different theoretical assumptions, is given here as an example and can be generalized. Results are obtained by running HSPA link budget tool for 2.1 GHz band, urban area, cell radius of 0.9Km and device category 14 [13].

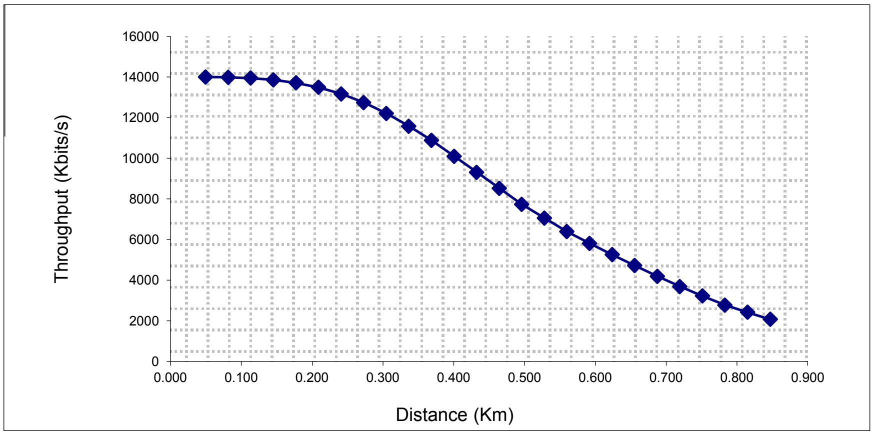


Figure 5. 2: Single User Throughput vs Distance [13].

5.1.1 Influence of traffic load

The example of throughputs presented in Figure above corresponds to a user that is alone in the cell. However, the radio interface is a shared broadcast medium with two important implications:

- Considering a given cell, the available radio resources (power, time slots, and codes) are shared among its active users. The result of this is that the throughputs experienced by users are almost equal to the throughputs, illustrated in Figure above divided by the number of active users.

- Considering the network as a whole, the broadcast nature of the radio channel makes the cells inter-dependent because of inter-cell interferences. Therefore, during busy periods, the interference from neighboring cells increases degrading the SINRs and thus user throughputs.

The traffic load has thus a direct influence on user throughput, via the resource sharing, as well as an indirect impact due to the increased level of inter-cell interference.

5.2 QoS and capacity dimensioning

5.3 QoS and capacity dimensioning

In the previous section, important KPIs (user and cell throughputs) related to the user satisfaction and the network loads are presented. However, if the aim is to dimension the network, these measurements alone are not sufficient and a more detailed analysis of the Quality of Service (QoS) is needed. Indeed, the objective of network dimensioning is to dimension network resources in order to offer a certain QoS to customers.

The present section will detail some QoS metrics and explain what are the factor impacting them and how they are related to capacity.

The objective of network dimensioning is to dimension network resources in order to offer a certain QoS to customers. This section details some QoS metrics and explain what are the factors impacting them and how they are related to capacity [13].

5.3.1 Offered services and the associated QoS

Mobile networks offer different types of services which may be classified into three main categories:

- **Elastic traffic**, e.g., mail, ftp, web, etc. In this case, users aim to transmit some volume of data at the bit-rate that is offered by the network. For these elastic connections, the QoS may be defined in terms of the mean throughput per user, or the throughput achieved by 95% of users [13].
- **Voice traffic**: Users require some constant bit-rate for some duration and the interactivity imposes stringent delay and jitter constraints. In this case the requested bit-rates may sometimes exceed the available capacity, a situation usually called congestion. As these services do not tolerate temporary interruptions of their transmissions. Consequently, if congestion occurs, the network blocks (i.e., refuses the access to) new calls and drops (i.e., interrupt definitely) some others during their transmissions [13]. The main QoS indicators are thus the blocking and dropping probabilities.
- **Streaming** calls such as mobile TV and YouTube. Usually, all streaming calls are admitted in the network, but, as a counterpart, they tolerate temporary interruptions of their transmission [35]. We distinguish two sub-classes:
    - Live Streaming: e.g., mobile TV, RTP streaming. When congestion occurs, insufficient throughput translates into packet losses for RTP/UDP based streaming services (bad audio quality) and/or buffering periods (for both RTP and HTTP based streaming services) where portions of some calls are definitely lost, but the call is not dropped.

- Video file Streaming: e.g., YouTube, daily motion, on demand video. When congestion occurs, the corresponding portions of calls are delayed.

For these streaming users, the QoS is related to the mean throughput obtained during the streaming session. The user is satisfied only if the throughput allocated by the network is the one required by the streaming flow. Notice that today most of the streaming sessions are adaptive, meaning that the codex bitrate of the video is adapted considering the radio condition to avoid buffering events [13].

Traffic Type	**Services**	**QoS requirements**	**QoS indicator**
Voice traffic		Very High	Blocking rate Dropping rate
Elastic traffic	mail, ftp, web browsing	Low	Average user throughput Cell edge user throughput
Video file Streaming	You tube, daily motion, on demand video	Medium	User satisfaction
Live streaming	mobile TV	High	User satisfaction

Table 5. 1: UMTS services and associated services [13].

5.3.2 QoS capacity and dimensioning

Based on the explanation of the previous sections, we understand that QoS is inversely related with load. However, a detailed analysis of QoS needs a characterization of the traffic mix and dynamics (calls' arrivals, mobility and departures). Indeed, traffic forecast is generally given using its average value (Erlangs for voice and Mbps for data). Traffic is bursty by nature and this burstiness may lead to local QoS degradation.

The figure below illustrates a simple example of a link of capacity C, where traffic demand bursts may make the total bandwidth demand exceed C for some times; this leads to temporary QoS degradation (blocking and dropping for voice calls, throughput degradation for data) [13]. Note that this is only an illustrative example in order to illustrate the impact of burstiness on QoS.

Figure 5. 3: A link subject to traffic bursts [13].

The capacity is defined as the maximal traffic demand such that the QoS remains satisfactory for the users. Estimating this capacity is very important since it gives the value of the traffic demand beyond which the operator should take actions mainly when network upgrade (such as densification or hardware extension) is needed.

Note that these QoS metrics are Key Performance Indicators (KPIs) that are related to user experience. Other KPIs such as load (power, TTI, code, Iub…) describe the congestion state of the network and are related to QoS KPIs (a higher congestion means a degraded QoS). These congested KPIs (easier to measure using OMC counters) can thus be used in the dimensioning and capacity estimation process, by replacing QoS targets by network congestion targets. An example of these network-related KPIs is the Seamless Wireless Access (SWA) congestion KPI, defined by a combination of the cell load and the number of active users and used to monitor the health of the 3G networks in the group [13]

5.4 Radio & hardware resources

The previous section presented the impact of radio conditions on the capacity. Next step is to present the capacity upgrade levers that are used for the dimensioning process.

The most impacting parameter on radio network capacity is the installed hardware resources. This essentially includes the number of activated 3G carriers and associated codes, power amplifiers, the number and capacity of installed Baseband boards (Channel Elements) and the backhaul capacity (Iub).A shortage in any of these resources may lead to QoS degradation (call blocking or dropping, low throughput).

5.4.1 Baseband Unit

The Baseband Unit (BBU) is responsible for the signal processing. It converts the base band signals into traffic channels and vice versa. The process capability of a BB module is measured in Channel Elements (CE) which is the dimensioning unit. The mapping between the type of Radio Access Bearer (RAB) and the associated number of CE is supplier dependent.

BBU are configured at NodeB level. Besides CE limitation, additional limitation (hardware or by license) may exist considering the supplier and board version such as [13]:

- maximum number of supported cells(some board types can only support limited number of cells(3,6 or 9 sector) this kind of limitation is vendor and hardware type dependent).
- maximum number of simultaneous connected users
- maximum throughput shared among the users
- Support of some features (HSDPA, HSUPA, Dual Carrier…)

5.4.2 Power Amplifiers

Alongside the BBU, Node-B is composed of Radio Frequency Unit (RFU). This unit is for signal reception and transmission in the radio interface. It is composed of one or several power amplifiers per sector.

The recommended baseline is to have 20 Watt per carrier. Even if increasing the RF power has no impact on coverage (that is generally uplink limited) it has some impact on capacity. This is especially true in noise-limited zones (deep indoor and rural areas), where increasing the power will allow a better Signal to Interference and Noise Ratio

(SINR) or equivalently Channel Quality Indicator (CQI) and so a better access probability and received throughput [13].

5.4.3 Codes

The radio interface of UTRAN uses WCDMA technology for transmission and reception. This means that the signal transmissions/receptions are spread over codes. The minimum spreading factor of WCDMA code tree is 256. Spread of these signals is based on the Orthogonal Variable Spreading Factor (OVSF) technique [13]. The use of OVSF codes allows the spreading factor to be changed (which allows adjusting bit rates) and orthogonality between different spreading codes of different lengths to be maintained.

5.4.4 Carriers

Adding carriers is the simplest and most efficient way to increase the capacity of a site. Indeed, adding a carrier means using new spectrum in the cell site (new orthogonal radio resources), and an automatic increase in the number of codes. Indeed, each carrier has its own radio scheduler and a site with two activated carriers has, roughly, twice the radio capacity than a site with one carrier. However, in order to profit at the maximum from the new carriers, some hardware upgrades may be required, depending on the original configuration of the site, for instance [13]:

- Adding a BBU for increasing the signal processing capabilities.
- Adding a power amplifier (or swapping the old PA by a new high power PA) in order to ensure, at least, 20 Watts per carrier.

- Increasing the Iub capacity, especially if the dual cell feature is to be activated.

5.4.5 Iub capacity:

The Iub bandwidth is composed of:

- The user plane: It is composed of Common and Dedicated Transport Channel data streams that are transferred between the Node B and RNC containing radio interface user data.
- The control plane: It consists in Node B Application Protocols (NBAP) and Access Link Control Application Part (ALCAP) for signaling and control.
- The node synchronization: It provides timing and supervision (O&M) of traffic frames between the Node B and RNC for both the uplink and downlink directions.

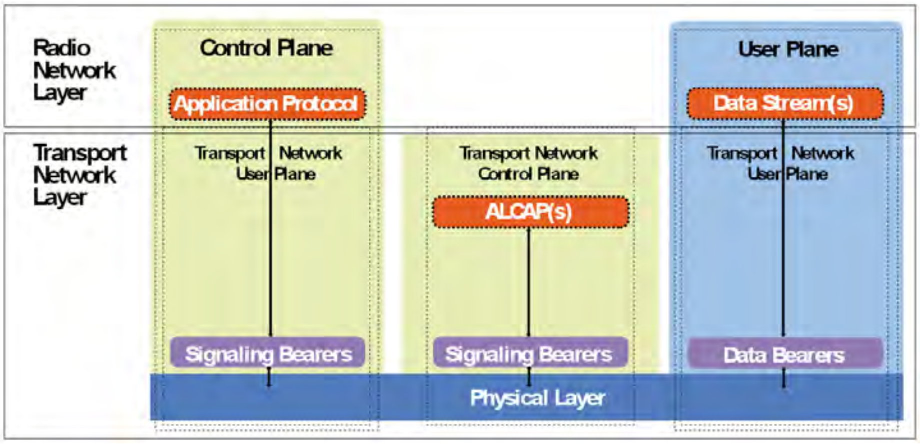


Figure 5. 4: General Protocol Model [13].

Three different transport options are possible:

- ATM based transport: the common option used in old generation network
- IP based transport: the recommended option for new sites
- Hybrid mode: transition mode where a part of the bearers are still routed over ATM (mainly Voice and Signaling) and others are routed over IP (data traffic).

Iub - ATM (user plane)	
Radio Network Layer	PDCP
	RLC
	MAC
	Iub FP (Frame Protocol)
Transmission Network Layer	AAL2
	ATM
	Physical Layer

Iub - IP (user plane)	
Radio Network Layer	PDCP
	RLC
	MAC
	Iub FP (Frame Protocol)
Transmission Network Layer	UDP
	IP
	Data Link Layer
	Physical Layer

Table 5. 2: Protocol stacks of ATM and IP [13].

The available Iub bandwidth is often one of the most limiting constraints in term of dimensioning and QoS. Indeed, a limited bandwidth on Iub could reach to blocking but more often it will prevent users to reach the maximum throughput offered by their device [13].

For example, sites with Dual Carrier feature activated, if Iub bandwidth is far below 42Mbps then users will not be able to reach this maximum (even if there are in very best condition - alone and close to the antenna).In the other side, for a 3 sectors configuration, it's not necessary to dimension the Iub to 3*42Mbps as it will be highly unlikely that 3 independent users will be able to get 42 Mbps on each sector at the very same time [29].

5.5 Impact of device categories and smartphones

This section explains the impact of the device mix (UE categories, smartphone/dongle split) on the capacity. The first HSDPA devices (categories 6 and 8) were limited in throughput capabilities and code consumption. The result was that these devices were not able to profit from all the resources offered by the network. However, new device categories starting from category 10, allow using more codes, higher order modulations and achieve thus larger throughputs, the mix of devices is thus of large importance regarding capacity [13].

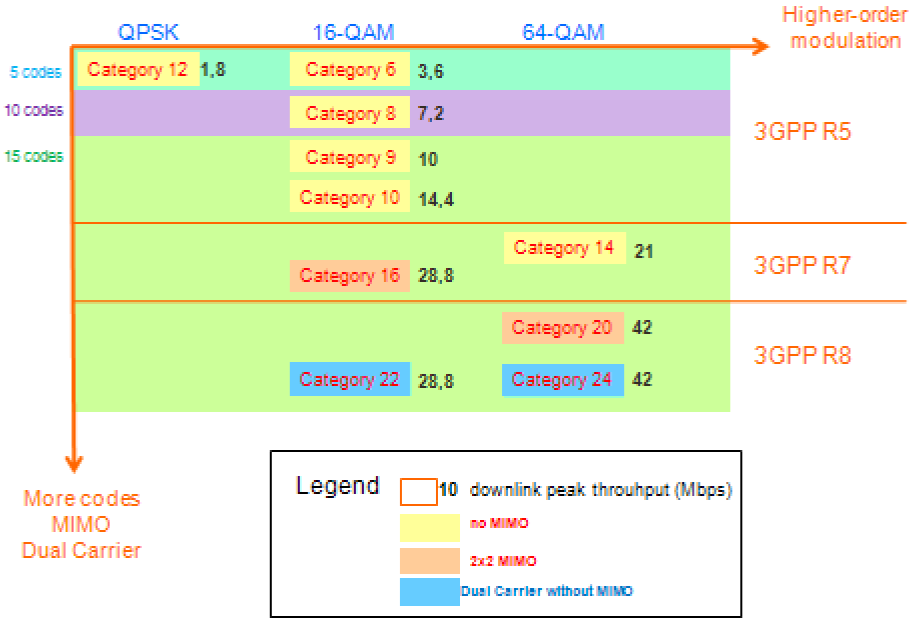


Figure 5. 5: HSDPA device categories [36].

It is worth noting that the device mix has to be taken into account when performing the dimensioning exercise, but the operational engineers have no means to influence it in order to enhance capacity.

The only exception is by activating hardware and software features (e.g. 64QAM, dual cell) that allow profiting from the capabilities of the available devices.

5.6 Impact of smartphones

For HSDPA services, behavior of the UEs can impact the available codes and Channel Elements. Indeed, it's proven that smartphones connect regularly to the network to transmit a very few amount of traffic (background traffic for notifications and push data). It generates a lot of signaling messages but also consumes cell resources as each established connection consumes some resources in codes and Channel Elements for their Signaling Radio Bearer (SRB) [13].

At the end, from the cell perspective, only a limited part of the connected users are really transmitting data. The others are only connected and are waiting for their inactivity timer to expire.

Chapter 6 Results and Conclusion

Network planning is a major task for operators. Especially the wireless network part has a vital importance to network quality of service. This planning and design work is time consuming, labor-intensive, and expensive. Moreover, it is an iterative process, which needs a new round of work with each step in the network's simulation and dimensioning activity. Additional planning and design works are necessary whenever there is a change in the environment: A new building can change the multipath environment, and a new shopping center requires additional new cell sites, and a new highway can create new hotspots. So we must make a good planning and design work at earlier stage, which is helpful for network expansion and service update in the future. Most importantly network planning requires engineers to analyze coverage, signal strength and availability of coverage holes in the intended area by using wireless planning tolls, and finally output the results of RF planning, including base station layout and scale that provides the good quality, coverage, and without interference.

6.1 Site location selection process.

Once the coverage and capacity dimensioning are finished the next step is to carryout prediction simulation activities in the planning tool to locate node B locations. Most of the time it is better to use existing site locations and resources as much as possible to avoid extra cost and to facilitate project rollout time. Hence new site location can be proposed if and only if the existing site quantity can't meet the target coverage and capacity requirements. During new site location selection process there are different principles that we should consider which will be discussed below.

General process for new site selection

- The network planning engineer generates a list of theoretical sites by using planning tool taking cell radius and hexagonal design as an input.
- The survey engineer makes a selection and survey according to the planned sites
- For a complex area, make a propagation test to check whether the coverage is ok
- After the site is selected contact the owner or landowner to check whether the site can be purchased or leased

Purpose of site selection is to select a site that can cover the target area and has the lowest interference to other sites.

Principles of site selection

- The sites should be laid out, with the allowed deviation not larger than ¼ of the BS radius
- The position of a new site should be place with convenient traffic and power supply
- At the early stage of the network construction, the most important area should be provided with good coverage
- When the site is in a mountainous area, near lake, sea or building with glass wall, the effect of signal reflection should be considered
- The site should not be built beside broadcasting station, radar station, or other interference source
- The coverage edge of the site should be within the high traffic density area

Site Selection in high density urban area

- The antenna should be lower than the average height of buildings in the area
- The antenna should not be blocked by any nearby building
- The antenna should be installed at the edge of the building

Site selection in urban area

- The antenna should be slightly higher than the average building in the area
- Line of sight links may exist in the most portion of the area covered by the BS

Site Selection in the suburb

- The antenna should be 5m to 10m higher than the average building in the area
- Line of sight links should be available in the most portion of the area covered by the BS
- Only some line of sight links cross the cell boarder

Site evaluation.

Wireless environment: The RF engineer should check the following issues on each candidate site and the nearby sites:

- Does the candidate site well cover the target area?
- Is there any RF interference on the candidate site?
- Is there any apparent barrier found in the photos or the map?

Transmission environment: The selection of a candidate site is affected by transmission planning:

- Is the optical fiber cable or E1 resource available?
- Is any line of sight link to the microwave node available?

Engineering Feasibility: the new site should facilitate the use of vehicle and lifting equipment

- Requirements on the building

- A safe and convenient passage
- The moving of the equipment to the site room through a lift or a goods elevator in the building should be easy.

Power supply: proper power supply should be available at the site

- The total power consumption of the main equipment and auxiliary equipment should be considered

This information's must be considered in the site selection and decision process. If there is adequate and up to date databases about geographical information's like clutter database, building information, street information's ,building material type, government owned buildings and locations(for faster land acquisition process), depth of building wall, nearby broadcasting stations, radar and interference sources, building heights, availability of power sources, availability of transmission resources, and availability of MW line of sight databases are available during the planning process, we can feed these information's to the planning tool to use it as an input and output criteria in the calculation and decision process of site location determination. For instance we can configure it to avoid roads, mountainous areas, lakes, seas or building with glass walls to be considered as a candidate positions in the site location calculation process. It is also possible to set filtering rules to make special re-planning like selecting higher buildings or very dense areas and set out specific cell radius and search radius so as to meet the requirement in that specific area. It is possible to create a single site/stations or a series of sites by defining an area on the map where you want to place the stations. Once the area where we want to place the series of stations is drawn on the digital map, the planning tool fills the delimited zone with new stations according to the defined hexagonal cell radius in the station template. The Automatic Cell Planning

(ACP) algorithm will automatically configures the cells with the defined cell parameters. This is the theoretic location, latitude & longitude and other parameter of sites. Based on this theoretic location of sites, a sites survey activity will be carried out to confirm site location, site type & location, antenna type, height, direction angle, down tilt etc. After considering the above points the final node B site location is shown in the figure below with 105 node B's distributed all over Bole Sub city

Once the location of node B's are identified, the next step is carrying to out prediction simulation in the planning tool. The objective of this prediction is to verify that, all the selected to be covered area is successfully covered with UMTS radio signal. As it is shown in the figure 6.2 the whole area is covered UMTS radio signals, with different colours representing different radio signal strength

As you can see from the prediction simulation result the selected area is covered with UMTS radio signal that means there is no coverage hole, which means you can find UMTS radio signal anywhere anyplace. According to the given input coverage probability requirement the minimum requirement to cover is 95% of the area. The coverage prediction result from the planning toll shows that more than 95% of the area is successfully covered with UMTS signal along with its required signal strength value.

The next step is to perform prediction by signal strength, the required signal strength is -80dbm for Dense urban, -85dbm for Urban and -90dbm for Sub urban. Prediction of Coverage by signal strength was also achieved above the required value as indicated in the figure below.

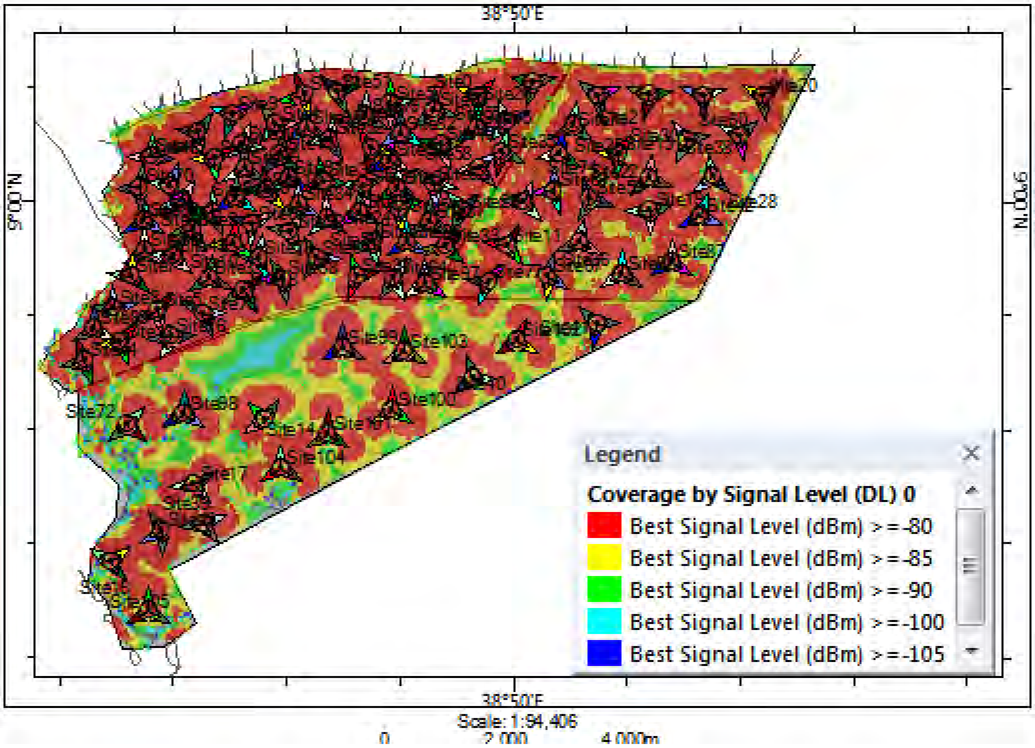
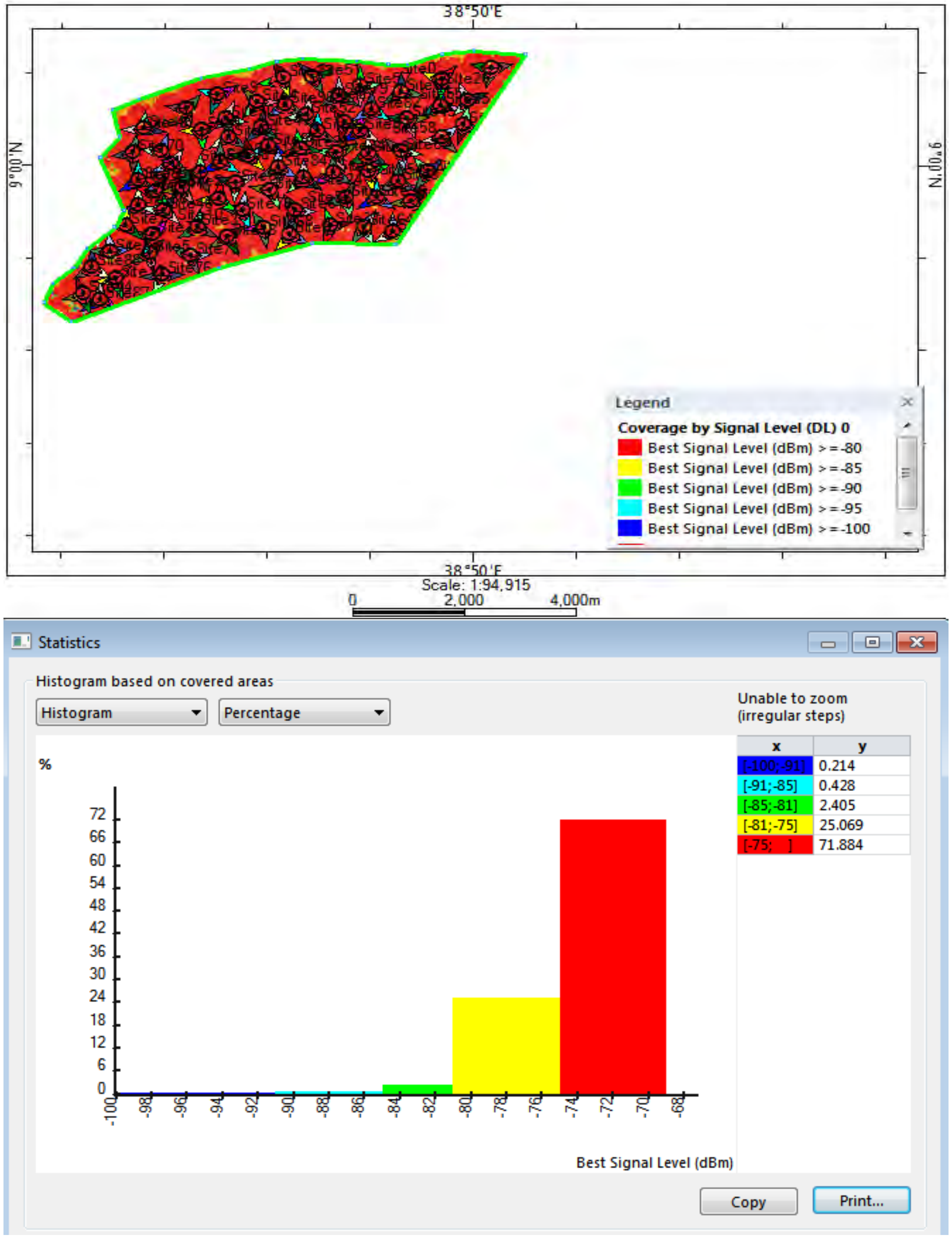


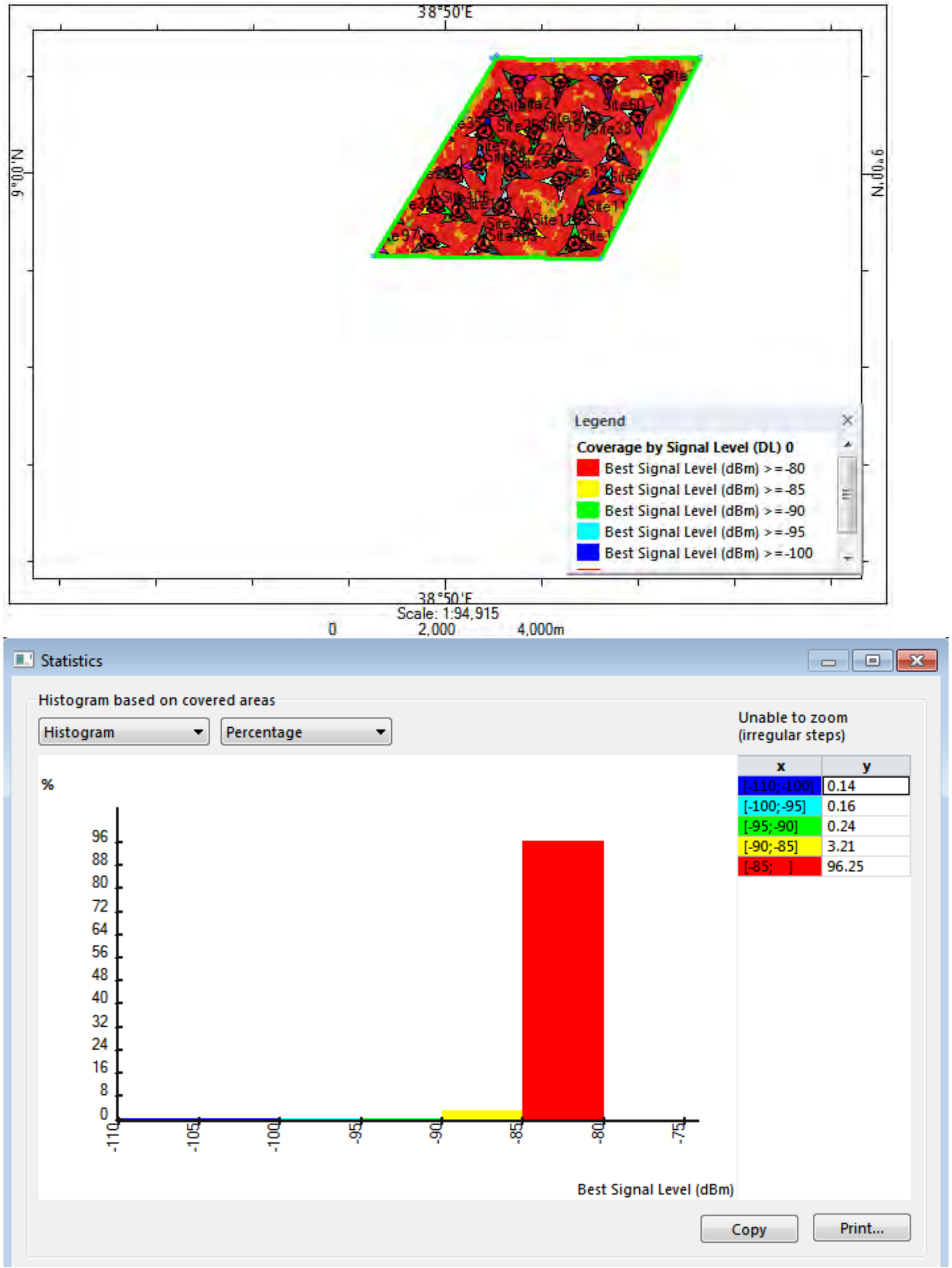
Figure 6. 1 Final Site location along with prediction by signal strength for Bole Sub City.

Prediction Outputs for different geographical locations.



x	y
[-100;-91]	0.214
[-91;-85]	0.428
[-85;-81]	2.405
[-81;-75]	25.069
[-75;]	71.884

Figure 6. 2 Dense Urban prediction by signal strength result.



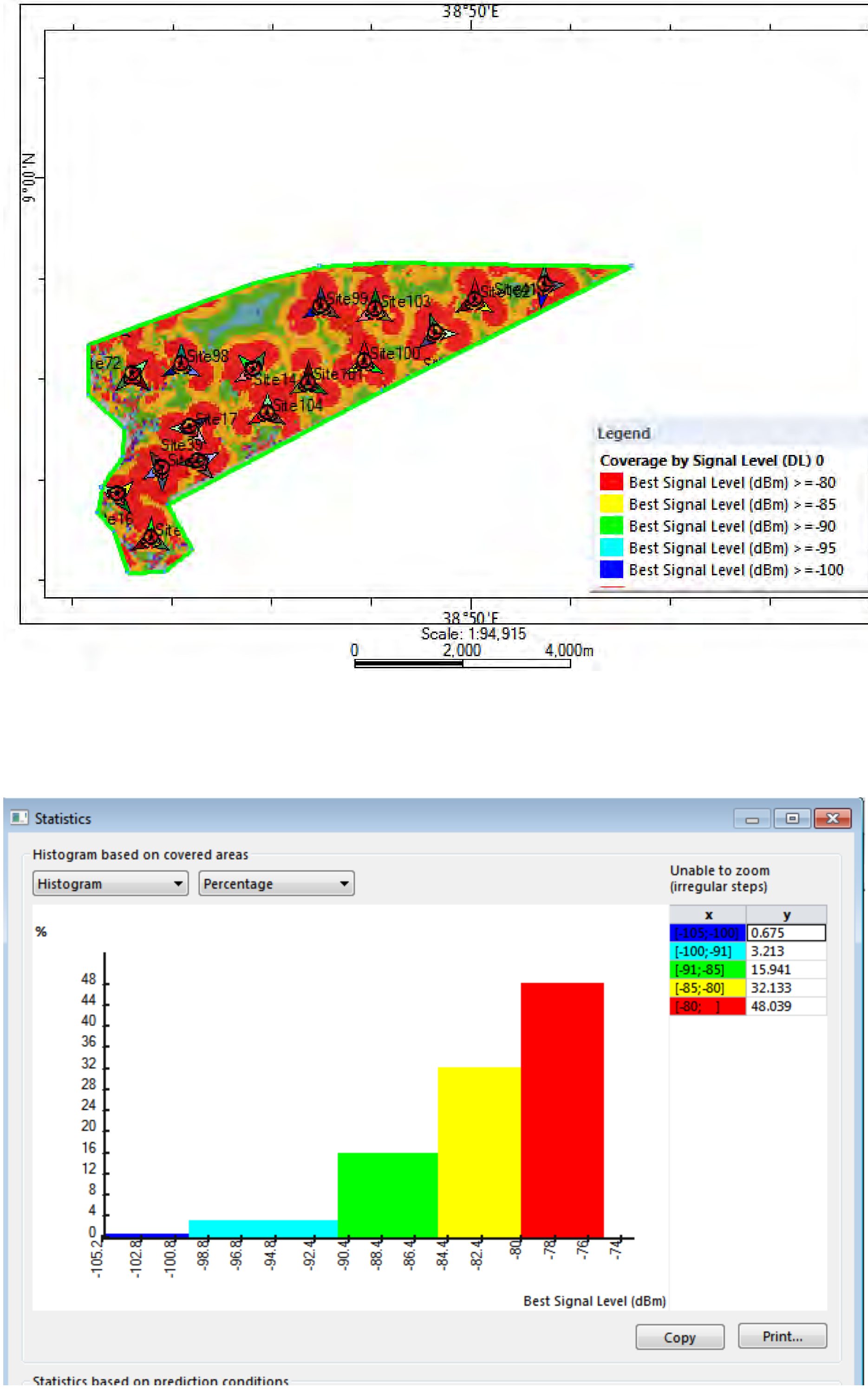
Legend

Coverage by Signal Level (DL) 0

- 🟥 Best Signal Level (dBm) >=-80
- 🟨 Best Signal Level (dBm) >=-85
- 🟩 Best Signal Level (dBm) >=-90
- 🟦 Best Signal Level (dBm) >=-95
- 🟦 Best Signal Level (dBm) >=-100

x	y
[-110;-100]	0.14
[-100;-95]	0.16
[-95;-90]	0.24
[-90;-85]	3.21
[-85;]	96.25

Figure 6. 3 Urban prediction by signal strength result.



Legend

Coverage by Signal Level (DL) 0

🟥 Best Signal Level (dBm) >=-80

🟨 Best Signal Level (dBm) >=-85

🟩 Best Signal Level (dBm) >=-90

🟦 Best Signal Level (dBm) >=-95

🟦 Best Signal Level (dBm) >=-100

Unable to zoom
(irregular steps)

x	y
[-105;-100]	0.675
[-100;-91]	3.213
[-91;-85]	15.941
[-85;-80]	32.133
[-80;]	48.039

Statistics based on prediction conditions

Figure 6. 4 Sub urban prediction by signal strength result.

The Red color in the figures 6.1,6.2,6.3 and 6.4 represents strength of greater than -80 dbm , that means areas covered with red color are those areas in which their signal power is very strong to get high data rate services is -80dbm for 95 % of the area. According to the prediction result around 96.953% (Red and yellow color)of the area is covered with signal with strength of greater than -80 dbm as indicated in figure 6.2. Which means its minimum requirement is achieved as per the requirement provided by the operator. For Urban area the minimum input requirement for signal strength is to cover 95 % of the urban area with signal strength of -85 dbm. The prediction output of the planning tool in figure 6.3 shows that around 96.25 %(Red color) of the area is covered with UMTS radio signal with a power strength value of greater than -85 dbm. The next part is the result about Sub urban area with a requirement of greater than -90dbm signal strength for 95% of the designated area. Just like dense urban and urban areas these requirement with achieved for 96.113 %(red, yellow and green color) of the sub urban area. To sum up even though the different designated areas have different signal strength value, their required requirements are meet successfully as per the operator equipment.

6.2 Recommendation for Future work.

The main objective of this thesis is to design a UMTS Radio frequency network in particular; Capacity planning and coverage for Bole sub City of Addis Ababa. Planning and design of Iub dimensioning (IP based transmission between Node B and RNC), dimensioning work regarding number of RNCs, PS and CS networks is out the scope of this thesis witch will be done as a future work.

6.3 Conclusions

UMTS brings new features, and services, which carry also new challenges, which needs to be solved. Radio network planning in UMTS has a high degree of complexity compared to GSM. Unlike GSM UMTS supports many types of bearer services, these services being characterized by their own unique properties, like bit rate, Bit Error Rate

(BER), blocking probability, maximum delay, etc, these are the properties which makes the planning and design work more complex.

From the cellular operator point of view, the main goals of planning and design is to minimize the financial cost by minimizing the number of Node B's with guaranteed quality of service and network capacity. In order to achieve this goal, some vital steps must be done, like the study of UMTS radio air interface, service features, optimization methods and traffic prediction.

This thesis focuses mainly on UMTS coverage and capacity planning which is intended to identify and describe the necessary steps which lead us in to finding our objective of planning a UMTS RF network. When we comes to our Country, there is a strong requirement for voice, data and broadband services across the country, to satisfy this demand EthioTelecom is carrying out extensive expansion projects to improve its capacity and coverage area. Now a day's technologies are evolving rapidly from time to time including user demand. In order to benefit from this advancement we need to have a well-designed and planned state of the art network.

When we come to design and planning work, for the sake of simplicity we can divide it into different phases. The first phase is the pre-planning phase; where the basic properties like scope of the project, service mixes, and coverage area of the future network are collected and investigated. The next step is the main planning phase, where the larger portion of the planning work will be done, like site locations of Node B's ,geographical properties estimated traffic volumes, link budget, capacity calculation will be done. The last step is where coverage Simulations and prediction will be done using Atoll wireless planning tool to evaluate the different possibilities to build up the 3G radio access network.

The coverage and the capacity planning are of essential importance in the whole radio network planning. The objective of coverage planning is to determine the service range, while that of capacity planning is to determine the number of Node B's and their respective configuration type. In this phase, intensive modification will be made to optimize the network. The simulated results will be examined and refined until the best compromise between all of the facts is achieved.

The result of this thesis shows that the required capacity, coverage and signal strength of the UMTS radio access network can be achieved with 105 node B (101 node B from capacity dimensioning result and 4 sites added to meet signal strength requirement),let alone with 113 node B's as per existing node B quantity in Ethiotelecom network. This result is less than by 8 Node B's compared to currently deployed amount in EthioTelecom network.Therefore this planning and design work reduces network and engineering design cost, equipment rollout cost, network operational cost, improved the beauty of the city by reducing number of to be deployed antenna towers. Hence not only it can satisfy the required coverage, capacity and signal strength value but it is also cheap, time saving and acceptable which can be used by EthioTelecom for future network expansion projects.

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