Department of Information Science and Technology

Optimization of the Methodology of Configuration of Mobile Communication Networks

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"[...]For whatever comes, come what may
Any day, friend, I'll meet you again.
Any day, my friend, we'll meet each other. [...]"
(Milton Nascimento)
"Song of America"

How can I forget those who have made a dream come true? How can I forget those who have seen in my happiness their true source of joy? Of course, I would be unfair if I did not mention the following important companions who shared this journey with me.

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To all my friends who, directly or indirectly, were always there to give me advice and encouragement. Today I know how friends are fundamental to guide us and help make good choices.

"[...]Today I feel stronger, happier who knows,
I just make sure that very little I know,
Or I know nothing [...]"

Almir Sater

Sumário

A rede de comunicação móvel tem crescido rapidamente e ficando cada vez mais complexa, sendo cada vez mais complicado melhorar o desempenho, a cobertura, a eficiência energética e ao mesmo tempo aumentar o numero de utilizadores e serviços. O provedor de serviços de telecomunicações e a operadora de rede móvel têm de se preocupar em optimizar de forma a garantir a melhor configuração de rede móvel tendo em vista melhorar a operação e funcionalidade, a fim de esta ser mais eficiente, no seu desempenho. Relativamente aos *aspectos técnicos* (Criar novo planeamento e integrar a uma rede ao nível hardware e de software), *aspecto econômico* (redução de custo na manutenção) e *aspecto ambiental* (uso de energia renovável, quer através de painéis solares como de sistemas eólicos).

O trabalho desenvolvido nesta dissertação visa propor uma otimização da metodologia de configuração das redes de comunicação móveis e construir um sistema de configuração automatizado em diferentes tecnologias (GSM, UMTS e LTE), para garantir os mais altos padrões de qualidade e atender a exigência de um grande número de serviços ou aplicações através de diferentes meios de transmissão e uso de tecnologia apropriada com uma nova geração de hardware para atingir determinada área em uma Estação de Transmissão de Base (BTS) e numa Rede de Controlador de Rádio (RNC) que permitem configurar e integrar diversos tipos de hardware e software em tecnologia de diferentes redes (GSM, UMTS e LTE).

O sistema de configuração automatizado dá destaque ao ponto de partida de modo a aumentar o desempenho e diminuir tempo de resposta, nessa investigação em otimizar e configurar a rede móvel rapidamente, que permitem autenticar remotamente no servidor de modo a ser possível configurar, integrar, criar e apagar as rotas de uma forma automatizada de um determinado site, quer em RNC e controlador de estação base (BSC).

Palavras-chave – Rede móvel de comunicações, otimização da metodologia de configuração GSM, UMTS e LTE, melhoria de desempenho, GSM, UMTS e LTE, Indicadores Chave de Desempenho, Controlador de Rede de Rádio, Controlador de Estação Base**.**

Abstract

The mobile communication network has been growing quickly, and the mobile network maintenance is becoming more complex, in performance, network coverage, energy, time consuming and expensive. The telecommunication service provider and mobile network telecommunication operator worries to what is the better methodology to optimizing a mobile network configuration and to improve the most efficient operation and functionality, to increase a superior performance in *technical aspect* (Create, and integrate new network planning in hardware and software level), *economic aspect* (cost reduction in maintenance) and *environmental aspect* (use of renewable energy through solar panels or wind power system).

The work developed in this dissertation aims to propose an optimization of methodology of configuration of mobile communication network and build an automated configuration system in different technology (GSM, UMTS and LTE) to provide a good quality and improvement in its architecture to meet the requirement for a large number of services or application through distinct means transmission and using technology appropriate with a new generation of hardware to reach certain area in a Base Station Transmition (BTS) and a Radio Network Controller (RNC) that permit configure and integrated hardware and software issues in distinct networks technology (GSM, UMTS and LTE).

The automated configuration system it also highlights, as the starting point for the research to increase the performance and answer time to optimized and configure the mobile network communication quickly, that allow authenticate remotely in server to configure, integrate, create and delete the automated routes of a site in distinct RNC and The Base Station Controller (BSC).

Keywords— Mobile network communication, GSM, UMTS and LTE optimization of methodology of configuration, GSM, UMTS and LTE performance improvement, Key Performance Indicators, Radio Network Controller, Base Station Controller.

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Acronyms

3GPP	3rd Generation Partnership Project
AAA	Authorization, Authentication and Accounting
AC	Authenticating Center
AMPS	Advanced Mobile Phone System
ATM	Asynchronous Transfer Model
BG	Border Gateway
BS	Base Station
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
CGN	Charging Gateway Node
CN	Core Network
EDGE	Enhanced Data rate for GSM Evolution
EIR	Equipment Identify Register
EPC	Evolved Packet Core
GGSN	Gateway GPRS Support Node
GMSC	Gateway Mobile Switching Center
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HARQ	Hybrid Automatic Repeat Request
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
IDE	Integrated Development Environment
IP	Internet Protocol
ISDN	Integrate Service Digital Network
KPI	Key Performance Indicator

LTE	Long Term Evolution
MAC	Media Access Control
MME	Mobility Management Entity
MSC	Mobile Switching Center
MTN	Mobile Network of Telecommunication
NAT	Network Address Translation
NE	Network Entities
P2P	Peer-to-Peer
PCS	Personal Communication System
PDCP	Packet Data Control Protocol
PDNGW	Packet Data Network Gateway
PS	Packet Switched
PSS	Public Safety & Security
PSTN	Public Switched Telephone Network
QoS	Quality of Services
RAN	Radio Access Network
RF	Radio Frequency
RLC	Radio Link Control
RNC	Radio Network Controller
RNO	Radio Frequency Network Optimization
RRM	Radio Resource Management
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SAE	System Architecture Evolution
SGW	Serving Gateway
TDMA	Time Division Multiple Access
TRX	Transceiver
UE	User
UI –	User Interface
UMTS	Universal Mobile Telecommunications System
VLBRs	Very Low Bit Rates
VLR	Visitor Location Register
WCDMA –	Wideband Code Division Multiple Access

CHAPTER 1 – INTRODUCTION

" All knowledge that does not lead to new questions quickly dies: it can not maintain the necessary temperature for the maintenance of life."
(Wislawa Szymborskam)
"The Poet and the World"

1.1. Motivation and Framework

For centuries, a question has remained in the minds of several researchers (engineers, technicians and scientists). Lengthy discussions and meetings are held to find out what is most important: knowing how to respond or knowing how to ask? After all, how a base station is interconnected to the terminal stations, what kind of services to transmit, how often and how much bandwidth to use, how to optimize the quality of service and quality of user experience. To answers such questions, you need to plan well and optimize better.

The electronic communication services supported by GSM / UMTS / LTE technologies in mobile communication systems, is one of means that the individual consumers and businesses are used to meet their daily communication needs, in particular in the telephone, messaging and data. In user perspective, the quality of service has an important and fundamental role by radio nature of access, the mobility they enable and the rate of utilization they present to cover each radio used by operators in the system of mobile communication [("Gsm/umts/lte," 2017)].

In temporary society, the demand for high speed Internet for mobile network communication system increased sharply, and the need for mobile broadband consumer access is happening, mostly due to the *High-Speed Packet Access (HSPA).* The "Network optimization is one of the key parts in the life cycle of mobile systems. For second- generation (2G) mobile networks, a series of standardized procedures have been defined for wireless network planning and optimization, while for third-generation (3G) mobile networks, researchers, and engineers are testing and improving the network planning and optimization methods/tools, both of them 2G and 3G mobile systems, network optimization should involve base station maintenance, signaling, testing,

adjustment, data collection, and analysis functions to improve coverage and reduce interference" (Hu, Zhang, Zheng, Yang, & Wu, 2010).

The four-generation (4G) mobile networks, "an advanced radio interface is used to the wireless systems were designed to fulfill the requirements of International Mobile Telecommunications- Advanced (IMT-A) using IP for all services, that can support data rates of up to 1 Gb/s for low mobility, such as nomadic/local wireless access, and up to 100 Mb/s for high mobility, such as mobile access. Using with orthogonal frequency-division multiplexing (OFDM), multiple-input multiple-output (MIMO), and link adaptation technologies" (Hu et al., 2010).

However, the deployment and optimization of mobile networks "are very complicated and challenging engineering tasks that require a comprehensive systematic approach. Conventional procedures usually are time consuming, require a lot of resources and man- power to achieve the goal. In future mobile networks, wherein multiple types of cells (*e.g.*, macro, micro, pico, and even femto) will coex- ist, an increasing number of parameters need to be taken into account in network optimization, so the challenges become much more intensive" (Hu et al., 2010).

The telecommunication network involves a "major change to provide a good quality improvement in its architecture to meet the requirement for a large number of services or application to improve the means of transmission in mobile communication via (Broadband, Multimedia, Video, IP, Mobile Phone, etc.), using the technologies appropriate to a new generation of hardware and powerful (radios, database, interfaces, service controllers, switches, new protocols, etc.) to manage video and voice data traffic in outgoing calls of a given existing telecommunication network" (INTERNATIONAL TELECOMMUNICATION UNION, 2008).

The optimization of mobile communication networks is becoming a different factor that applies in a methodology for the configuration of mobile communication networks, because it is a critical aspect from the *technical* point of view (Create and integrate new network planning in hardware and software), *economic* (cost reduction in maintenance) and environmental (use of renewable energy through solar panels or wind power system). For, the optimization of the methodology of configuration of the mobile

communication networks has been a constant concern, both for the companies that provide telecommunication services and for the mobile telecommunications operators.

The focus of this research is based on the use of the methodology of configuration of mobile communication networks for *GSM*, *UMTS* and *LTE* technology in the *technical*, *economic and environmental* a*spect*. And we build an automated configuration system, that allow you to authenticate the RNC and BSC user and password to connect remotely with the server to create implement, integrate the new site and configure the Base Station Controller (BSC) and Radio Network Controller (RNC).

A key point that motivates this research resides in the fact that optimization of the methodology of configuration of the mobile communication networks is in a certain way an incentive of ever deeper investigations in the knowledge and improvement for the telecommunication services provider and mobile telecommunication operator.

1.2. Objective

This dissertation aims to propose an optimized methodology in the configuration of mobile communication networks, for *GSM, UMTS* and *LTE* technology and develop the system of configuration automated. To achieve this goal, it is necessary to understand how a mobile communication network works, mainly in the configurations and integrations of the mobile communication networks, in the transitions of a technology to another. The entire process of mobile communication using *GSM, UMTS and LTE* technologies governs an analysis, planning, implementation and optimization to improve the quality of mobile network operation in technologies.

Telecommunications companies are often concerned with the use of different tools, *i.e.*, different packages integrated in a single platform for network planning. To improve network performance generally depends on companies providing software update services with modern technologies (GSM, UMTS and LTE).

The optimization of a network is one of the most efficient means in the operation of a network in the technical, economic and environmental aspect, which allows to implement, configure and integrate, both at the hardware level and at the software level, allowing to evaluate Key Performance Indicated (KPIs) , *e.g.*, number of users to be included, increase of powers and carriers, modernization of hardware, change and update of the type of transmission media, change of interfaces and creation of the list of adjacent base stations, in order to minimize the interference between to base stations and terminal stations.

1.3. Research Questions

To achieve the general objective of this research, the following specific objectives were drawn:

- What is the difference between planning and operating a communication system using GSM, UMTS and LTE technology?
- What is the criterion of analysis and advantage in the implementation of an LTE antenna to integrate the GSM and UMTS technology?
- What are the most important *Key Performance Indicators (KPIs)* for characterizing system performance?
- What possible settings can be made at base stations?
- What methodology should be used to optimize the base station configuration?
- What possible optimization is the methodology followed?
- What is the criterion of analysis in the implementation of one of the LTE technology?

1.4. Research Methodology

The research method that will be used in the scope of this project is demonstrated in five distinct phases:

1st phase: Objectives definition – At this stage, a set of telecommunication technologies and mechanisms are studied deeply to determine the impact on the transition of the technologies *GSM*, *UMTS* and *LTE* performance in telecommunication area. At the end of this phase, the objectives will guide the investigation to plan all the steps needed to develop the project.

2nd phase: Project development – At this stage, the different components of the project are developed to achieve the objectives of this project to increase mobility and performance, such as:

- Automated design architecture System to increase the performance in the analyze of the capacity;
- Implementation of remote authentication system for automated configuration;
- Creating and structuring a database for information storage;
- Development of an automated application to configure telecommunications networks for *GSM*, *UMTS* and *LTE* technologies to analyze the capacity of performance, the coverage to provide the mobility to mobile telecommunication system and for different functionalities.

3rd phase: Project implementation – The components mentioned in the second phase should be implemented together, following step by step to create a prototype of the project.

4th phase: Test the project – In this phase a set of tests is performed on the system to check for possible system errors and make changes and adjustments if necessary in the final prototype.

5th phase: Evaluation – At this stage the final prototype of the project must be tested and evaluated

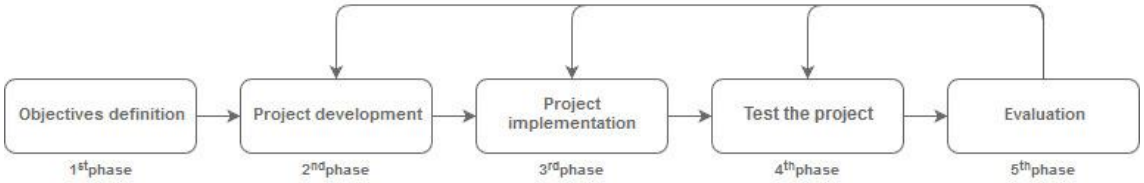

Figure 1 - Research method flow

1.5. Structure of Dissertation

This dissertation is organized in five chapters that intend to reflect the distinct phases as follows:

- ***Chapter 1:*** Present an overview of the dissertation from the point of view of its planning and organization. Through it is presented the context, motivations, objectives and research method employed.
- ***Chapter 2****:* Present a description of literature review of mobile network telecommunication configuration technologies *GSM, UMTS* and *LTE*.
- ***Chapter 3****:* Present the software engineer architecture of the automatized system developed to mobile network telecommunication configuration technologies *GSM, UMTS* and *LTE*.
- ***Chapter 4:*** Present describes the architecture and technology functionality operation of the automated configuration system tool considering capacity planning.
- ***Chapter 5:*** Present the result and KPIs analysis of the mobile network telecommunication system functionality tool and also, to planning and integrated the system configuration of network operator.
- ***Chapter 6:*** Present the main conclusion of this research and the future works.

CHAPTER 2 – LITERATURE REVIEW

"All knowledge demands a concept, however imperfect or obscure it may be."

(Emmanuel Kant)
"Critique of Pure Reason"

2.1. The Network of Mobile Telecommunication System

The different technologies are used for network mobile system since 80s until current time. "In 1983, the system *Advanced Mobile Phone System (AMPS*) standard, is available for public use and analogue to the *first generation (1G*), there were three main lines of development of digital cellular systems in USA, where operated in 850 MHz only for voice transmission" (Laiho, Wacker, & Novosad, 2005).

In the 90s emerged the 3-system based in *second generation (2G*), the first system is "*Time Division Multiple Access (TDMA*), used two frequency bands: 800 and 1900 MHz with narrowband voice was converted to digital and compressed, and is 3x times faster than the *AMPS.* The second system is Global System Mobile Communications (GSM) is most popular, and the frequency is like the TDMA with 900 and 1800 MHz, what has changed was the use of encryption, to make connections safer, more than this GSM technology introduced the SIM cards, the chips where they store the information of the phones. And the third system and latest generation is *Code Division Multiple Access (CDMA*), un like to the TDMA and GSM, the CDMA works in broadband, after converting the voice signal digital, the system CDMA divides the information into several packets and distributes across the available bandwidth, so many calls can travel across the entire bandwidth used at the same time, the only similarity to TDMA are the frequency bands: 800 and 1900 MHz" (Communications, 1997).

And before reaching 3G, we passed an intermediate phase of this 2.5G evolution, "before telephony allows voice communication, but as we all know the mobile telephony, it enables the exchange of messages and texts and internet access. these possibilities have become realities from the 2G standards but have begun to attract users broadly with 2.5G. Other systems have emerged in these GPRS intervals it allows the

transport of packet data, and in theory offered a fixed transfer that would exceed the mark of 170 Kbps, or bits per second, but usually does not reach 80 Kbps, focus here is the internet connection and data transfer, thanks to IP protocol compatibility. Another evolution was *Enhanced Data Rates for GSM (EDGE*), specifications are very similar to *GPRS*, but the maximum speed has risen to 473 Kbps, and the *EDGE* is recognized as standard 2.75G" (Meyer & Allee, n.d.).

To reach the third-generation (3G), the globalization has its impact also in the cellular world. In addition, a strong drive towards wireless Internet access through mobile terminals has generated a need for a universal standard, which became known as the *UMTS*.

These new 3G, "like W-CDMA one of the standards chosen for 3G technology, is a standard for radiofrequency in the same CDMA communication concepts, but the speed of connection and much higher reaching 2 Megabits per second (Mbps) and the HSPA technology that theoretically reaches 7.2 Mbps, these networks are being developed by integrating the features of telecommunications- and *Internet Protocol (IP*) based networks. Networks based on IP, initially designed to support data communication, have begun to carry streaming traffic like voice/sound, though with limited voice quality and delays that are hard to control" (Laiho et al., 2005).

The 4G - it knows the technology adopted the *Long-Term Evolution (LTE*), "the LTE calls attention by the maximum speed can reach 300 Mbps, another important thing is the frequency of the channel, the higher the frequency the greater the data transfer. LTE advanced is already spoken with rates up to 1 Gigabits per second (Gbps), it can work with several frequency bands around 2,5 GHz" (Yuan, Zhang, Wang, & Yang, 2010).

The overview of telecommunication network system, there are several "network elements in the radio network and these elements can be categorized to *radio access network* (*RAN*) and *core network* (*CN*). The RAN differs a little in each technology generation, but mainly it could be said that it includes base stations and controller elements for the base stations. Shortly the core network includes gateway elements for accessing traditional *PSTN* or the internet. Access to PSTN happens through circuit

switched (CS) CN where the connection forms an end-to-end circuit between the callers" (Engineering, 2015).

The access to the Internet and other IP-based (Internet Protocol) services is routed through packet switched (PS) core network, where all the information is transferred in IP-packets.

The "network elements have seen huge development during the last twenty years, from large and dedicated devices to smaller and more universal devices. In future plans this means that most parts of the network are going to be virtualized to cloud servers. The goal of this development direction is to cut the network costs and improve scalability" (Engineering, 2015).

Nokia's answer for this "future is called liquid net; it consists of liquid broadband, liquid radio and liquid core. In practice this means the virtualization of core network and network elements" (Engineering, 2015).

2.1.1. The GSM Network Communication System

The GSM network system communication industry throughout the world, with the frequency are 900 and 1800 MHz and use of encryption to make connections safer, it also introduced the SIM cards, the chips where they store the information of the phones. And "is investing in the design and manufacturing of advanced mobile Internet/multimedia-capable wireless network based on the *Wideband Code Division Multiple Access* (*WCDMA*) radio access platform. While current 2G wireless networks, in particular the extremely successful and widespread global GSM-based cellular systems, will continue to evolve and to bring such facilities as new Internet packet data services onto the market" (Laiho et al., 2005).

With a great advance in communication technology, the 2G technology needed to improve the communication in distinct coverage area to the customers, and "the telecommunication provider has created the opportunity for mobile terminals to receive many services that were, until not long ago, only available to tethered terminals. And to support large scale mobility, was the advanced mobile phone system. A new digital system, *Personal Communication System (PCS*) provides voice as well as data services to wireless users. *PCS* works in the *GSM* 800/1900 MHz spectrum. And there are competitive standards for analog, digital, and *PCS* system throughout the world" (Mallikharjuna, M, & -, 2012).

The GSM network mobile is composed by many kinds of equipment, that increase the performance and functionality in mobile network communication in "*Home Location Register (HLR*) switch, that maintains the profiles of entire subscribes that register with the home network. And when the mobile subscriber roams to another area, it has register with the *Visitor Location Register (VLR*) switch, that maintains a pointer to the *VLR* with currently serve the mobile and *VLR* also support registration, authentication, and call routing to a mobile while it`s away from its home area. And each *MSC* has a *VLR* to holds the reliant for handling calls from or to the *MSS* that are currently located in its area" (Mallikharjuna et al., 2012).

The *Base Station Subsystem (BSS*), is the group of equipment that goes from the *BSC* to the mobile phone side. It is composed mainly by *BTS*, *BSC*, *MSC* and transmission network to link them all. The "*BTS* radiates the *Radio Frequency (RF*) signal to the mobile phones and receive its signal back. This *RF* is radiated by antennas in the top of towers or buildings, creating coverage areas called cells. The geographical allocation of *BTS* is guided by *RF* coverage and traffic demand" (Pinheiro, Aguiar, & Pinheiro, 2010).

The "BSC are small telephony switches that control the BTS. Its goal is to create an additional level in the network hierarchy and increase the efficiency, based on the statistical gain. It is an exclusivity of GSM system. An IS-136 and CDMA family hasn't this equipment. And its links with BTS are E1 lines that holds voice channels slots configured deterministically in a one-to-one basis with BTS's radio channels slots. It is called Abis interface" (Pinheiro et al., 2010).

On the other hand, "BSC's trunks with MSC are E1 lines dimensioned by the total traffic from all of its BTS. It is called A interface. These trunks are similar to trunks between two MSC or other telephony switches. The voice channels in these cases are seized statistically and it varies with the hours. All calls must pass through the MSC, even when both subscribers are close, in the same BSC coverage" (Pinheiro et al., 2010).

The great challenging tasks in *GSM* equipment environment, is to maintain efficiently the *BTS*, *BSC*, *MSC* equipment maintenance because, it has a great cost in *technical aspect* (Create and integrate new network planning in hardware and software level), *economic aspect* (cost reduction in maintenance) and *environmental aspect* (use of renewable energy through solar panels or wind power system) to increase a superior performance to mobile network communication provider. And other challenging work of maintenance, "is the coverage aspect in certain area, this make the RF engineer's look for high altitudes and free of obstacles sites to reach larger distances, in traffic aspect, hotspots are focused with a *BTS* full equipped with radio channels in a limited and controlled *RF* radiation. And the *BTS* proximity is limited by interference in an urban area, because since there are a limited number of *RF* channels and they are repeated on and on, this make the *BTS* sites are allocated in a triangular grid pattern,

where it is possible divide to the three cells of each *BTS* that formed by the coverage of tree groups on antennas, disposed with 120º angle between then" (Pinheiro et al., 2010).

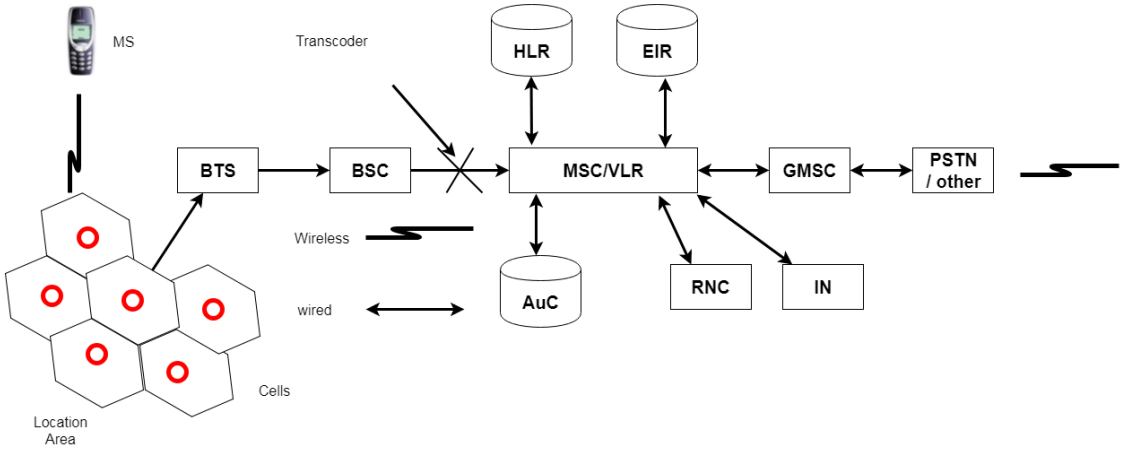

Figure 2 – The GSM Architecture (Mallikharjuna, 2012)[1]

The *Figure 2* present the *GSM* architecture where we each component of equipment has its functionality like as,

- The *" Mobile Switching Center (MSC*) Responsible for switching the voice or data connection to the mobile host" (Mallikharjuna et al., 2012).
- The " *Gateway Mobile Switching Center (GMSC*) which can route the calls from *Public Switched Telephone Network (PSTN*)" (Mallikharjuna et al., 2012).
- The "*Base Station (BS*), is the gateway between the wireless network and wired network. It provides the wireless connection to the mobile subscribers within its coverage area (Cell). A set of base stations are connected to the MSC through a Base Station controller" (Mallikharjuna et al., 2012).
- The "*Authenticating Center (AC* or *AuC*) is a workstation system, which authenticates subscribers. *AuC* needs to access user information for authentication process so it is co-located with HLR" (Mallikharjuna et al., 2012).

[1] Image taken from the: https://arxiv.org/ftp/arxiv/papers/1204/1204.1596.pdf

- The "*Equipment Identify Register (EIR*) it is a database which stores information for the identification of mobile units" (Mallikharjuna et al., 2012).

- The *"PSTN* this component refers to the regular wired line telecommunication network which is commonly accessed by landline calls" (Mallikharjuna et al., 2012).

The second generation of cellular technologies it also "covers the whole network architecture from radio access to core network. The acronym GERAN is more specific and stands for GSM/EDGE Radio Access Network. In practice this means the technology between mobile terminal and the base station" (Engineering, 2015).

The *GERAN* architecture is illustrated in Figure3, where we see the *Base Transceiver Station* (*BTS*) and the *Base Station Controller* (*BSC*) elements to communicate with the Core network travelling to the *CS Core* to get high rate of voice traffic communication and *PS Core* to get high rate of data traffic.

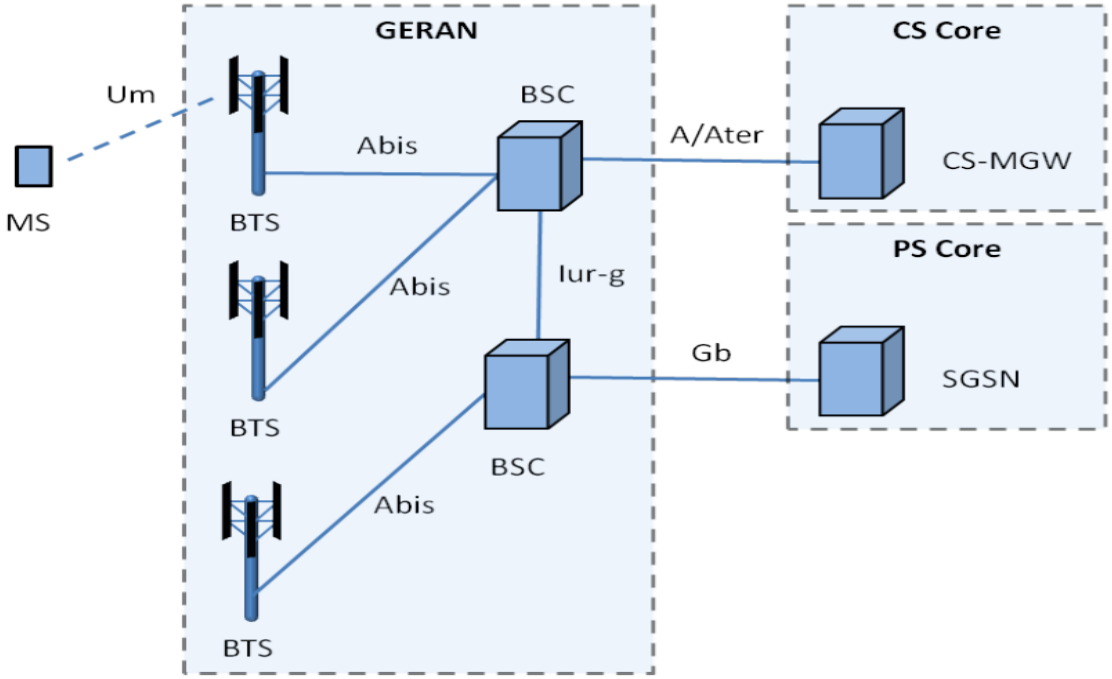

Figure 3 - GERAN system architecture da Internet (NSN 2013)[2]

The Figure 3 shows the communication relationships between "the GSM network components are described by a number of standardized interfaces. These interfaces can

[2] Imagem retirada do site: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

be used for managing the data transfers or controlling the connections in mobility management" (Engineering, 2015).

To understand the interfaces of GERAN system, lest see the description:

- **BTS** contains transmitter and receiver equipment, such as antennas and amplifiers.
- **BSC** contains protocol functions for radio channel allocation, channel setup and management of handovers. Typically, one BSC handles hundreds of BTS.
- **Um**, an interface between MS and BTS, target to provide access to the network.
- **Abis**, an "interface between BTS and BSC. It is used for controlling the radio equipment and radio frequency allocation in the BTS. The Abis interface also carries synchronization information from the BSC to the BTS and MS" (Engineering, 2015).
- **Iur-g**, an interface between two BSCs.
- **Gb**, an "interface between GERAN and SGSN. The Gb interface enables communication between SGSN and MS" (Engineering, 2015).
- **A/Ater**, A is "an interface between BSC and CS-MGW. It is used for signaling and carrying traffic channels. Ater is an interface between BSC and transcoder, it carries the A interface information from the BSC leaving it untouched" (Engineering, 2015).

The 2G contains three major technology categories; GSM, GPRS and EDGE. The "GSM technology is dedicated to speech calls and GPRS and its successor EDGE to packet data. While these technologies start to be outdated, GSM still is one of the best options for speech, mainly because of its wide cell coverage and simple implementation" (Engineering, 2015).

2.1.2. The UMTS Network Communication System

The *3G* network communication system based in "2G mobile network communication system, that have enabled voice traffic to go wireless. And it has been the features have helped 2G systems to spread rapidly around the world, with very high cellular phone penetration rates in many countries. The cellular networks have enabled certain types of communication to take place on a massive scale that previously were not possible or were at least severely limited" (Laiho et al., 2005).

With limited functionality in 2G makes the *3G* "merge paging, cordless telephones, mobile terrestrial, and mobile satellite standards into a single unified standard. And video coding at *Very Low Bit Rates(VLBRs*), in the range of a few tens of kilobits per second, is becoming very attractive for a number of new applications, such as mobile video communication, video telephony on the *PSTN*, multimedia electronic mail, and remote sensing, and for interactive data bases" (Gill, Cosmas, & Pearmain, 2000).

The "ability to transport compressed audio and video over mobile links will open up new areas of opportunity for services not yet commercially developed and provide the incentive to migrate from *GSM* to *UMTS* networks. And communications can be provided rapidly where there is an urgent need, in the form of mobile terminals, without the costly overhead of cable provision" (Gill et al., 2000). This causes the huge growth of mobile subscribers worldwide during the last decade, backed by an increasing demand for higher transmission rates and flexible access to diverse services, makes telecommunication provider introduces very variable data rates on the air interface, as well as the independence of the radio access infrastructure and the service platform.

"That motivated significant research, standardization, and development in mobile communication systems, and the main objective of future wireless networks is to provide universal ubiquitous coverage across different radio technologies through a single terminal, while offering a rich range of services with variable bandwidth and *QoS* (*quality of service*), anytime, anywhere" (Al-Gizawi, Peppas, Axiotis, Protonotarios, & Lazarakis, 2005).

The following years were spent on optimizing UMTS system specifications, handset and network implementations, and mobile applications has been increasing in many kind of functionality and with increase of quality need for customers. The *WCDMA* has been able to bring tangible benefits to operators in terms of network quality, voice capacity, and new data service capabilities.

The 3G cellular networks communication system that has been standardized by "3*rd Generation Partnership Project (*3*GPP*) have already gained significant customer base in many countries. And the *3GPP* feature was gradually deployed to the evolution from *GSM* to *EDGE* to *3G/WCDMA* and *HSPA, to* enhancing network capacities, the 3GPP has played a key role in such wide-spread deployment that have already gone through several updates with respect to handling packet data connections" (Perälä, Barbuzzi, Boggia, & Pentikousis, 2009). And 3GPP technologies provide an excellent overview to "introduced *High Speed Downlink Packet Access (HSDPA*), a major enhancement to the downlink channel, with nominal peak data rates of 14.4 Mb/s. And, the uplink packet data connection was upgraded as well with the introduction of *High Speed Uplink Packet Access (HSUPA*). When used together, these enhancements form a technology referred to as *HSPA*" (Holma, Toskala, & Wiley InterScience (Online service, 2009).

And the *3GPP* has an intent "to offer enhanced multimedia services to mobile users at high data rates, the systems are expected to be initially deployed in dense subscriber areas covered by *GSM*/*GPRS* (e.g., city centers, shopping malls) to augment the capacity and deployments of these existing *GSM/GPRS* networks to display the result. Hence, one of the critical features in the initial deployments of *UMTS* networks is the inter-system functionality between *UMTS* and GSM/GPRS. Efficient inter-working between *UMTS* and *GSM*/*GPRS* systems will be crucial to provide continuous service coverage to dual-mode mobiles" (Saravanant, Sreenivasulu, Jayaram, & Chockalingam, 2007).

The "*WCDMA* networks were launched during 2002. By the end of 2005 there were 100 open *WCDMA* networks and a total of over 150 operators having frequency licenses for *WCDMA* operation. Currently, the *WCDMA* networks are deployed in Universal *Mobile Telecommunications System (UMTS*) band around 2GHz in Europe

and Asia including Japan and Korea. WCDMA in America is deployed in the existing 850 and 1900 spectrum allocations while the new 3G band at 1700/2100 is expected to be available in the near future. *3GPP* has defined the WCDMA operation also for several additional bands, which are expected to be taken into use during the coming years" (Speed, Access, & Communications, n.d.).

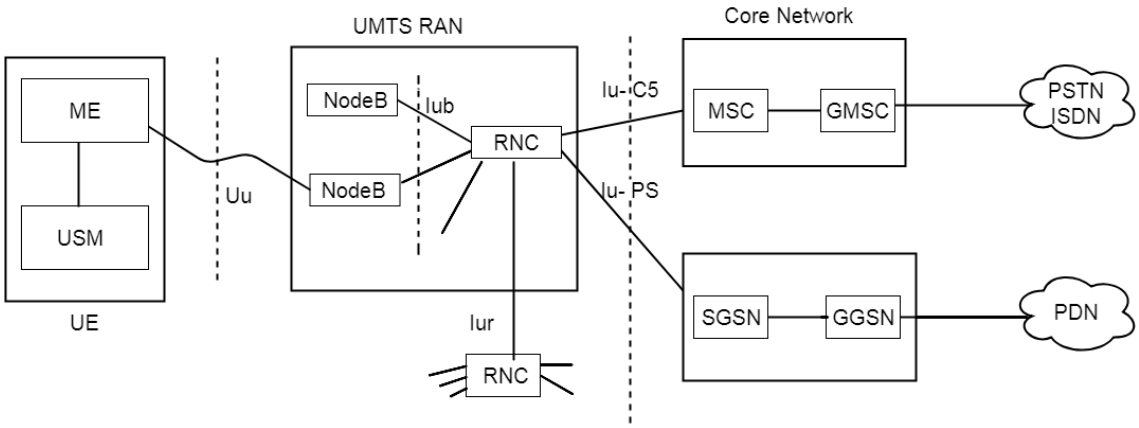

Figure 4 – The UMTS Architecture (*RF WIRELESS, 2017*)[3]

The Figure 4 present the *UMTS* architecture where we each component of equipment has its functionality like as,

- The *user (UE)* has very high-speed RF connection to the nearest local tower, and the high-speed connections is always ON, as long as mobile is powered up.
- The *"Mobile Switching Center (MSC*) Responsible for switching the voice or data connection to the mobile host" (Mallikharjuna et al., 2012).
- The "*Gateway Mobile Switching Center (GMSC*) which can route the calls from *PSTN*" (Mallikharjuna et al., 2012).
- The *RNC* performs radio specific tasks, such as it converts packets into radio frames and vice versa, manages the radio resources, and controls handover.
- The *"PSTN* this component refers to the regular wired line telecommunication network which is commonly accessed by landline calls" (Mallikharjuna et al., 2012).

[3] Imagem retirada do site: http://www.rfwireless-world.com/Tutorials/UMTS-Network-Architecture.html

- The *Gateway GPRS Support Node (GGSN*) provides interworking with packet data networks and is connected with other core network nodes via an IP-based packet domain PLMN backbone network.
- The *Integrate Service Digital Network (ISDN*)
- The SGSN contains mechanisms for avoiding and handling overload situations. In an overload situation the SGSN can request the RNC to reduce any kind of signaling traffic as specified in TS.

The goal of 3G was to offer a greater spectral efficiency and bandwidth for growing telecommunication markets, and the Radio Access Network functionality are Similarly, as in GERAN, UTRAN is the radio technology used between mobile terminal and base stations.

The 3G offered a huge improvement in data rates when compared to 2G, but "it also increased complexity on the network planning side. The reason for complexity is that in 3G, every user is generating interference for the other users, because all share the common frequency band. Another 3G-specific thing is cell breathing, this means that the cell size is increasing and decreasing depending on the number of users in the cell" (Engineering, 2015).

The UTRAN network architecture and its elements are illustrated in Figure 5.

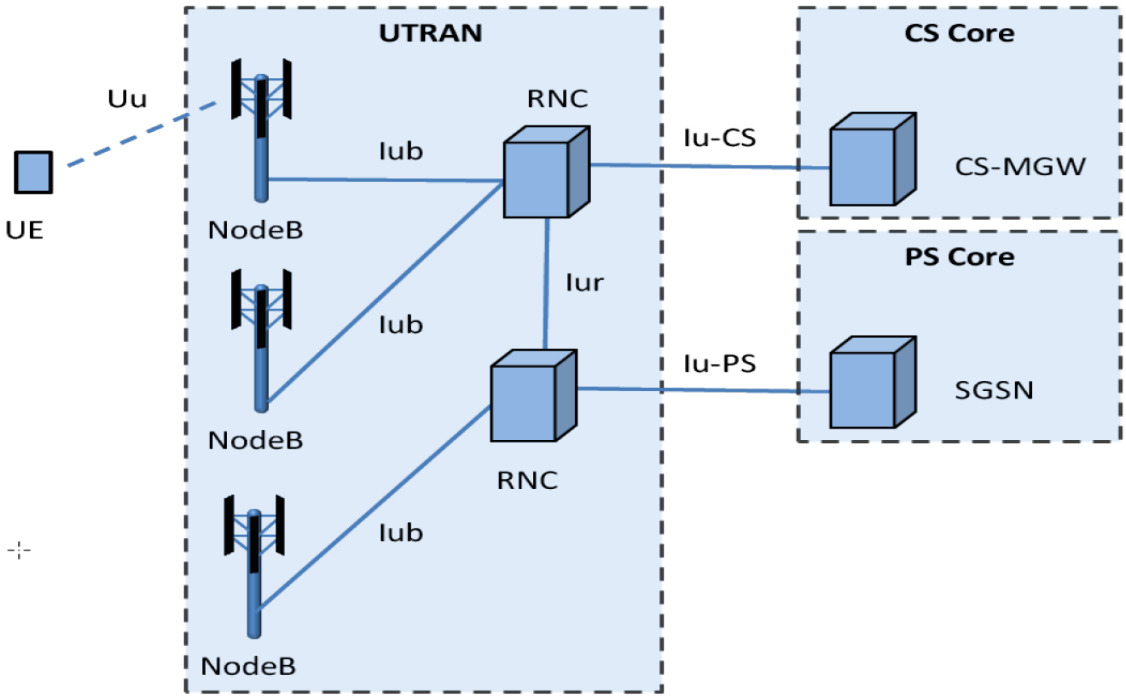

Figure 5 - UTRAN system architecture (NSN 2013)[4]

The Figure 5 shows the control plane in UTRAN includes the application protocols and the signaling bearers, which transport the control information to describe the UTRAN network element like as:

- **NodeB** means the same as the base station. "It's task is to convert the data flow between Iub and Uu interfaces and participate to radio resource management".(Engineering, 2015)
- **Radio Network Controller** (RNC**)** owns and controls the radio resources in its domain. It also works as a connection point for core network services.
- **Uu**, is the WCDMA radio interface, through Uu UE can access the network.
- **Iub**, is a logical interface between a NodeB and a RNC.
- **Iur**, is an interface that enables soft handovers between RNCs from different manufacturers.
- **Iu-CS** connects UTRAN to CS core network and enables circuit switched mobile calls.

[4] Imagem retirada do site: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

- **Iu-PS** connects UTRAN to PS core network and enables access to Internet.

The presented integration architecture for UMTS and WLAN. The “WLANs in hotspot areas form micro-cells within UMTS macro-cells. The architecture allows a mobile node to maintain data rate (PS) connection through WLAN and telephony voice rate (CS) connection through UMTS in parallel. This is especially attractive because WLAN is currently used primarily for high-speed best-effort data service” (Speed et al., n.d.).

2.1.3. The LTE Network Communication System

The demand for high speed internet for mobile communication system increased sharply, and the need for mobile broadband consumer access is happening, mostly due to the *HSPA* and *LTE.*

The "Network optimization is one of the key parts in the life cycle of mobile systems. For second- generation (2G) mobile networks, a series of standardized procedures have been defined for wireless network planning and optimization, while for third-generation (3G) mobile networks, researchers, and engineers are testing and improving the network planning and optimization methods/tools, both of them 2G and 3G mobile systems, network optimization should involve base station maintenance, signaling, testing, adjustment, data collection, and analysis functions to improve coverage and reduce interference. However, the deployment and optimization of mobile networks are very complicated and challenging engineering tasks that require a comprehensive systematic approach. Conventional procedures usually are time consuming, require a lot of resources and man- power to achieve the goal. In future mobile networks, wherein multiple types of cells (*e.g*., macro, micro, pico, and even femto) will coex- ist, an increasing number of parameters need to be taken into account in network optimization, so the challenges become much more intensive." (Hu et al., 2010).

The optimization of mobile communication networks is becoming a different factor that applies in a methodology for the configuration of mobile communication networks, because it`s a critical *aspect in technical* point of view (Create and integrate new network planning in hardware and software), *economic* (cost reduction in maintenance) *and environmental* (use of renewable energy through solar panels or wind system). Owing to the fact that, the optimization of the methodology of configuration of the mobile communication networks has been a constant concern, for both companies which provide telecommunication services, and mobile telecommunications operators.

The Ips Packet Optimization Network Architecture are deployed to develop of more efficient network architecture that concern in optimization of methodology of configuration of mobile communication networks to increased data rates, improved spectrum efficiency, improved coverage, and reduced latency. Those will allow carriers

to provide more data and voice services over a given bandwidth and reduce the operator cost in variety of traffic scenarios and automatization in sites on *RNC* and *BSC*.

The "LTE has a 'flat', all-IP based core network with a simplified architecture, open interface and fewer system nodes. Indeed, the all-IP based network architecture together with the new *Radio access Network (RAN)* reduces network latency, improved system performance and provide interoperability with existing 3GPP and non-3GPP technologies" (Sheriff, 2011). Within "3GPP, all-IP based core network architecture is now known as *Evolved Packet Core (EPC)*. EPC is the result of standardization work within 3GPP which targeted to convert the existing *System Architecture Evolution (SAE)* to an all-IP system" (Holma, Kristensson, Salonen, & Toskala, 2008).

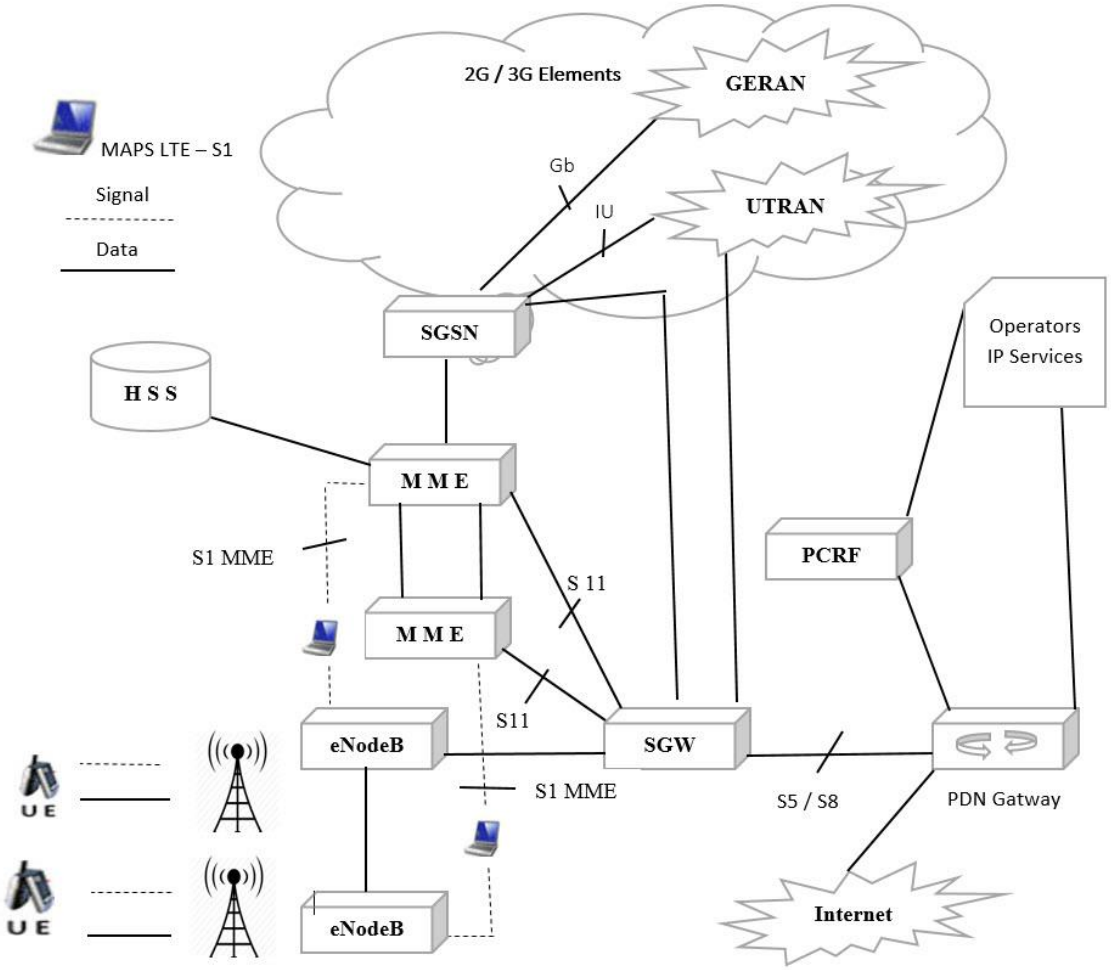

Figure 6 – The LTE Architecture

The Figure 6 depicts the internals LTE network. The *UE* has very high-speed RF connection to the nearest local tower, and the high-speed connections is always ON, as

long as mobile is powered up. The LTE is an all IP infrastructure with service priority built in audio and video are given priority. All necessities like Authentication, security and IP address are validated

The "*evolved RAN* consists of the LTE base station (eNodeB) that interfaces with the UE. The eNodeB contains the PHY, *Media Access Control (MAC)*, *Radio Link Control (RLC)*, and *Packet Data Control Protocol (PDCP)* layers. Therefore, the eNodeB performs some tasks such as resource management, admission control, scheduling and enforcement of negotiated UL *Quality of services (QoS)*" (Fernando & Pepinosa, 2013).

The "*Serving Gateway (SGW)* guides and forwards user data packets. Furthermore, during inter-eNodeB handover SGW acts as the mobility anchor for the user plane. It can also act as an anchor for mobility between LTE technology and other 3GPP technologies. When the UE is in idle state, the SGW terminates the DL data path of the UE and triggers paging when DL data arrives for the UE" (Holma et al., 2008).

The "*Mobility Management Entity (MME)* handles Control Signaling, for UE tracking and paging procedure that includes retransmissions" (Holma et al., 2008). MME is also involved in the bearer activation/deactivation process. "In addition, MME can choose the SGW for a UE at the initial attach and at time of intra-LTE handover involving *core Network (CN)* node relocation. MME can interact with the *Home Subscriber Server (HSS)* so as to authenticate the user" (Holma et al., 2008).

The *Packet Data Network Gateway (PDN GW)* is a point of exit and entry of traffic for the UE. PDN GW performs packet filtering and acts as the anchor for mobility between 3GPP and non-3GPP technologies such as WiMAX and 3GPP2. (Holma et al., 2008).

The network upgrading to LTE generation evolve changes in mobile communications have traditionally been evolutionary path to higher speeds and reduced latency to networks, the deployment and design of LTE is based on 3GPP family of cellular network that dominate by *GSM, General Packet Radio Service (GPRS)* and *Enhanced Data rate for GSM Evolution (EDGE)* as well as *WCDMA* and *HSPA.*

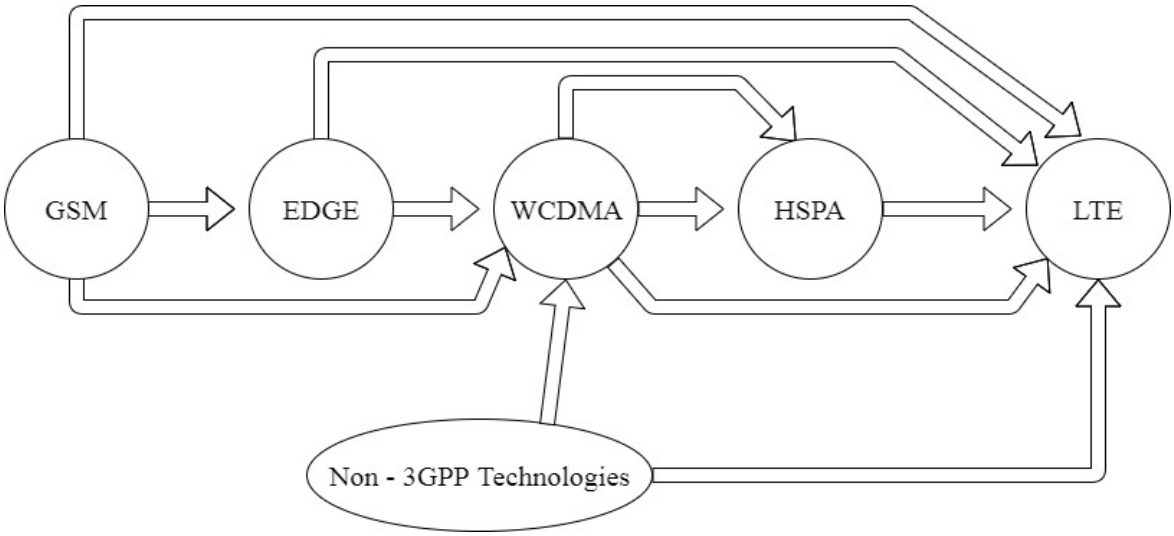

Figure 7 – The LTE Upgrading flow

The LTE network evolution is that “deploy hybrid packet/circuit switched networks, and other evolution, is in uses of the advanced new radio interface such as all IP environment architecture, to harness the full potential of LTE it requires an evolution from the existing network architecture ta a simplified. This evolution has advantages to operator`s to include reduced costs for variety of services, blended applications combining voice, video and data services plus interworking with other fixed and wireless networks” (Fernando & Pepinosa, 2013).

“Since the design of LTE is based on UMTS/HSPA family of standards, it will obvious enhance the capabilities of the existing cellular network technologies to delivery broadband services which were accustomed to fixed broadband networks. In other words, LTE will unify voice-oriented environment mobile networks with the data centric services possibilities of the fixed internet to the operator’s point of view, the smooth upgrading of the existing networks to LTE will allow the introduction of LTE’s all-IP concept progressively. As such operator will be able to retain the value of its existing voice-based service platforms at the same time getting the benefit of high performance in data services delivered by LTE network” (Fernando & Pepinosa, 2013).

The one of goal of LTE has been to provide even higher data rates than 3G and improve the spectrum efficiency while lowering the network operation costs. As a difference to older technologies, in “LTE all the data is IP based packet data, which also means that LTE does not have *Circuit Switched* (*CS*) Core. At the moment this also creates a drawback for LTE. When a user establishes or receives a call in an LTE

network, the mobile device has to do a CS Fallback procedure and switch back to 2G or 3G network to be able to do so. In future this is changing with the *Voice over LTE* (*VoLTE*) technology which enables IP based calls in the LTE network" (Engineering, 2015).

The LTE introduced *Evolved Packet Core* (*EPC*) which "should handle the data traffic efficiently in terms of performance and costs while having a simplified flat architecture. One of the major improvements in EPC is the separation of the user and the control planes, which makes the network scaling more independent and easier for the operators" (Engineering, 2015).

The LTE network and EPC can be seen in Figure6 below where we can explain each element in Figure 8.

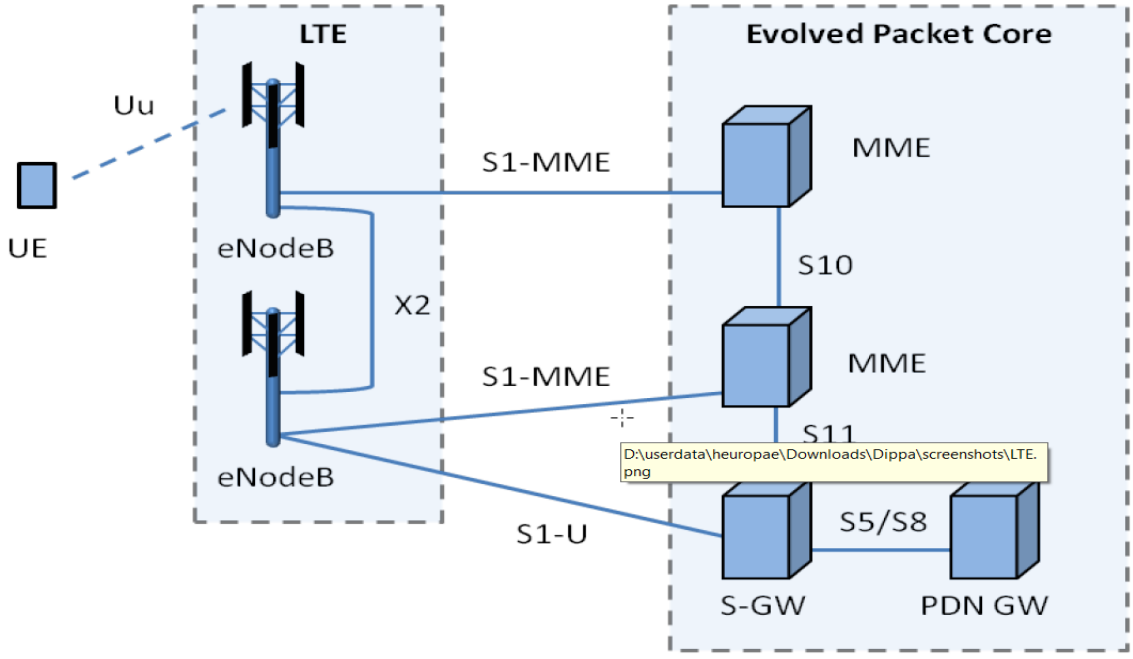

Figure 8 - LTE system architecture (NSN 2013)[5]

The Figure 8 shows the control plane interfaces in LTE architecture as important way to understanding the function of the elements in the network. The control plane

[5] Imagem retirada do site: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

interfaces also describe functionality between two network elements and it`s ease to understanding the relations in the network like as:

- **Evolved NodeB** (eNodeB) is "the LTE element equivalent to BTS and NodeB but differs in the sense that eNodeB has radio resource control, radio mobility management and full layer 2 protocol support features" (Engineering, 2015).
- **Mobile Management Entity** (MME) is used for the control plane functions related to subscriber and session management.
- **Serving Gateway** (SGW) is used as a "connection point of the packet data to-wards Evolved UMTS Terrestrial Access Network (E-UTRAN). In practice this means that the S-GW enables mobility between E-UTRAN and other 3GPP technologies" (Engineering, 2015).
- **Packet Data Network Gateway** (PDN GW) is functioning similarly as SGW and works as a termination point of the packet data interface towards the packet data network.
- **S10** is an interface between MME and another MME; it is used between MMEs for MME relocation and MME to MME information transfer.
- **S11** is an interface between MME and SGW, its target is to function as a reference point between MME and Serving GW.
- **S5 or S8** are interfaces "between SGW and PGW. S5 provides user plane tunneling and tunnel management between SGW and PGW. S8 is an inter-PLMN reference point providing the user and control planes between the SGW in the visitor PLMN and the PGW in the home PLMN" (Engineering, 2015).
- **S1-U** is an interface "between eNodeB and SGW, and it is used between E-UTRAN and Serving GW for the per bearer user plane tunneling and inter eNodeB path switching during handover" (Engineering, 2015).
- **S1-MME** is an interface "between eNodeB and MME, it is a reference point for the control plane protocol between E-UTRAN and MME" (Engineering, 2015).
- **X2** is an "interface between two eNodeBs, it can be used for signaling and handling radio resources between the base stations" (Engineering, 2015).

- **Uu** is an "interface between eNodeB and UE, its target is to provide data transfer between eNodeB and UE" (Engineering, 2015).

The GSM, UMTS and LTE are similar in many ways in the sense that they inherit most of the elements implemented in the "GSM/GPRS and EDGE architecture while changing the names of the elements. A Major similarity is the fact that they all implement radio access points and they use cellular technology; another similarity is that they all employ the use of the HLR as the subscriber database although it is called the Home Subscriber Server (HSS) in LTE. The differences between most of the technologies are based on the evolvement of the core elements and the access methodologies, bandwidths and modulation types. The table below is used to give a better comparative analysis between the technologies" (Ochang & Irving, 2016).

Table 1 – Comparison of GSM, UMTS and LTE features (Ochang 2016)[6].

Description	GSM	UMTS	LTE
Access Methodology	TDMA/FDMA	WCDMA	OFDMA/ SC-FDMA
Maximun Downlink Speed [kbps]	10-150	384	100000
Maximun Uplink Speed [kbps]	10-150	128	50000
Bandwidth[kbps]	200	5 000	1.4 to 20 000
Modulation Types Supported	GMSK	QPSK	QPSK, 16QAM, 64QAM
Core Network Type	Circuit Switched	Circuit/packet Switched	Fully IP based

I must conclude that the mobile network communication system mainly cellular technologies, have experienced a tremendous growth and change in their architectural design and this change has been very significant in the core of the network. The "network core has fully evolved from a circuit switched core to an all IP based core which means that with the advent of future cellular technologies, IP packets can be used to carry cellular network traffic therefore enhancing traffic management and providing

[6] table taken from the:
https://www.online.journals.tubitak.gov.tr/openAcceptedDocument.htm?fileID=290882&no=61310

better quality of service" (Ochang & Irving, 2016). And based on this analysis this means that they will be advanced support for services such as multimedia streaming. Integration with other telecommunication infrastructure such as Voice over Internet Protocol (VoIP) will provide an interesting area of research. Therefore, further research can be carried out in other to provide a clear overview of how VoIP can be integrated into the IP core of advanced future cellular technologies.

2.1.4. Core Network

The *core network* (*CN*) "means the backbone of the telecommunication networks. It has also evolved during the technological advancement from 2G to LTE and the direction at the moment is towards the liquid core, meaning virtualization and cloud services. The key features of core networks are aggregation, authentication, call control or switching, charging, service invocation and gateways to other services" (Engineering, 2015).

The CN introduced the different ways in architecture of functionalities in each technology (GSM, UMTS and LTE) comparing both of them. The "GSM core architecture relied on circuit switching until the GPRS was introduced; it added packet switching to circuit switching, which enabled the transportation of packets without establishing dedicated circuits. When UMTS was released, it evolved some network elements but mainly it kept this dual domain concept in the core network. And the LTE has introduced an evolved packet core and by doing so, it has simplified the core network architecture" (Engineering, 2015).

The Figure 9 shows the circuit and packet domains.

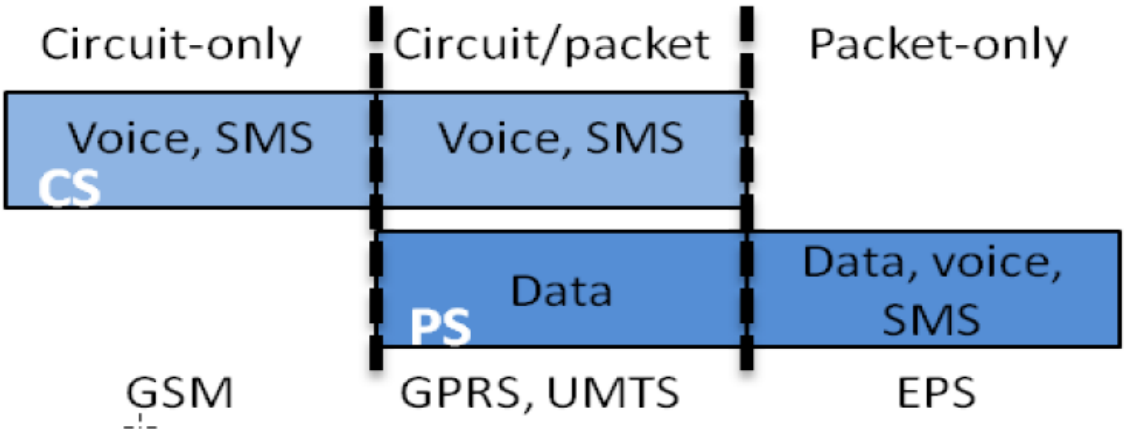

Figure 9 - Circuit and packet domains (NSN 2013)[7]

The Figure 9 shows the circuit and packet domains where the registers and PS/CS core network elements are described below.

[7] Imagem retirada do site: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

- **Circuit Switch Media Gateway** (CS-MGW) is “a node which handles CS connection capacity and handles all physical connection matters”(Engineering, 2015).
- **Mobile Switching Center** (MSC Server) is “a switch that serves the UE in its current location for circuit-switched services. MSC also contains visitor location register (*VLR*) database” (Engineering, 2015).
- **Gateway MSC** (*GMSC* Server) is “the switch at the point where public land mobile network (*PLMN*) is connected to external circuit switched networks. All incoming and outgoing circuit switched connections go through *GMSC*” (Engineering, 2015).
- **Authorization, Authentication and Accounting** (AAA) is “a register that authenticates and authorizes the subscriber’s network access. *AAA* is also responsible for subscriber billing” (Engineering, 2015).
- **Equipment Identity Register** (EIR) “contains information about terminal equipment and can be used for blocking specific terminals from network” (Engineering, 2015).
- **Home Subscriber Server / Authentication Center** (HSS/AuC) presents “the registers such as home location register (HLR). The function of HSS is to provide information about user’s service priorities and data rates. AuC part of the HSS is used for generating security information from user identity keys, which then is used for network terminal authentication” (Engineering, 2015).
- **Serving GPRS Support Node** (SGSN) has a similar functionality as MSC but is used for packet switched services.
- **Charging Gateway Node** (CGN) collects charging data from PS domain elements and relays them to the billing center to be post processed.
- **Gateway GPRS Support Node** (GGSN) PS counterpart for GMSC.
- **Border Gateway** (BG) is a gateway which enables roaming between two separate PS domains belonging to separate network.
- **Public Switched Telephone Network** (PSTN) means the traditional wired tele-phone network.

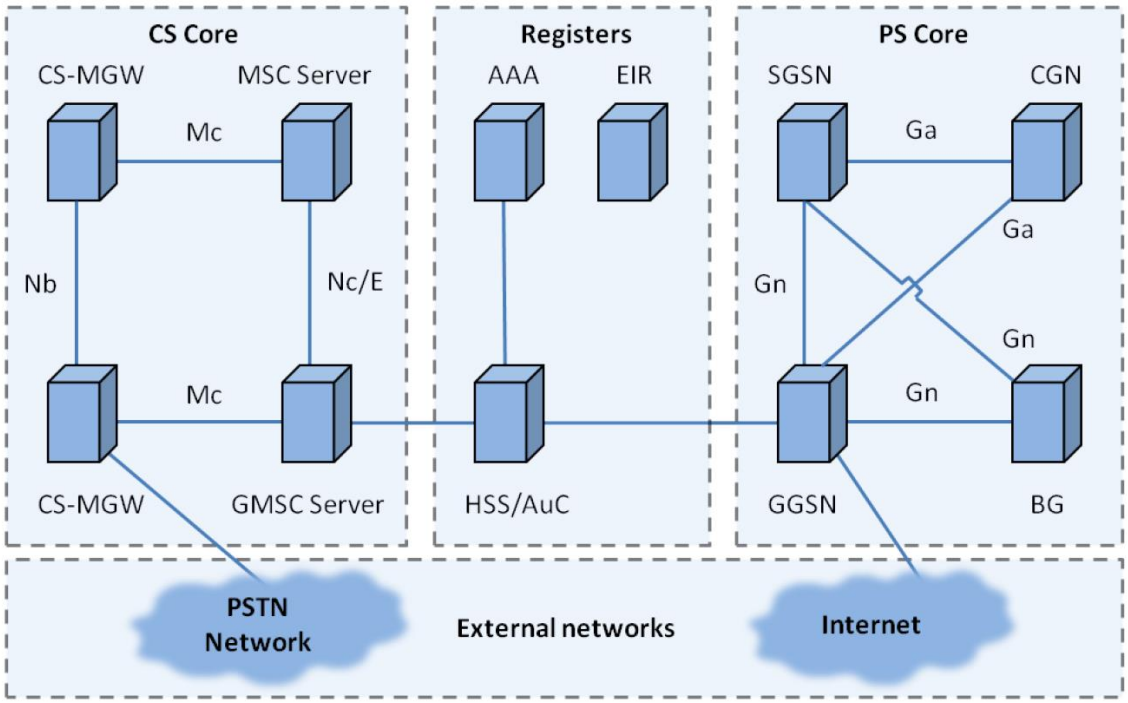

Figure 10 - Registers, CS and PS Core architecture (NSN 2013)[8]

The Figure 10 shows the register CS and PS core architecture interfaces "in the core network, that describe the connection or function between two different elements in a similar way as with radio networks. Generally, the interfaces in core networks are used for control purposes" (Engineering, 2015).

The Figure10 are explained the interfaces functionalities list:

- **Nb**, an interface between two media gateways. It is used for bearer control and transport.
- **Mc**, an "interface between an MSC or TSC and its controlled MGWs. It is used for the separation of call control entities from bearer control entities and vice versa"(Engineering, 2015).
- The **Nc/E** interfaces are "between two MSCs or TSCs. An Nc interface is used for network-to-network based call control. The E interface is used for handover purposes when mobile user is changing or moving from one MSC area to another during the call" (Engineering, 2015).

[8] Imagem retirada do site: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

- The **Ga** interface is between GSN and CGN. It is used for offline charging purposes.
- **Gn**, an interface used to carry signaling and data traffic between GSNs.

2.1.5. Network Adjacency

The Network adjacencies mean in "practice that a network element is next to another network element and they have some kind of relation. In Figure11 shows the adjacency with a graph below, in which *BTS A* is adjacent to *BTSs B* and *C*. In the network, an adjacency can be used for controlling purposes, *i.e.* handovers between two technologies or between used frequencies" (Engineering, 2015).

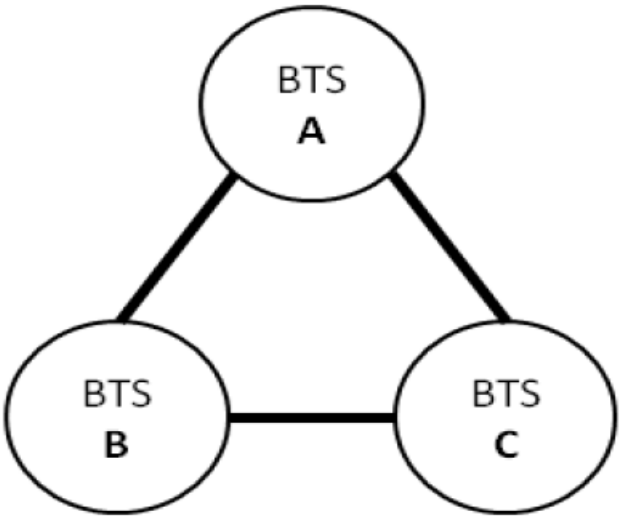

Figure 11- Undirected adjacency graph example (NSN 2013)[9]

Both 3G and LTE have several different adjacencies, and in both technologies, there are different terms for describing the adjacencies. The description below explained the adjacencies functionalities:

- **ADJS**, Intra frequency adjacency, "used for controlling intra-frequency handovers. Intra-frequency handovers in WCDMA are soft handovers" (Engineering, 2015).
- **ADJI**, inter frequency adjacency, "used for controlling inter frequency handovers. Inter frequency handovers in WCDMA are hard handovers" (Engineering, 2015).
- **ADJD**, Additional adjacent cell.

[9] Imagem retirada do site: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

- **ADJG**, Inter system adjacency, "used for controlling handovers from WCDMA to GSM" (Engineering, 2015).
- **LNADJ**, neighboring LTE BTS.
- **LNADJL**, neighboring LTE BTS cell.
- **LNADJW**, neighboring WCDMA BTS cell.
- **LNADJG**, neighboring GERAN BTS cell.
- **LNADJX**, neighboring CDMA 1xRTT BTS cell.
- **LNADJT**, neighboring TD CDMA BTS cell.
- **LNREL**, LTE neighbor relation.
- **LNRELG**, LTE neighboring GERAN relation.
- **LNRELW**, LTE neighboring WCDMA relation.
- **LNRELX**, neighboring CDMA 1xRTT BTS cell.
- **LNRELT**, neighboring TD CDMA BTS relation.

These adjacencies are important for NetAct tool in performance testing, because adjacencies determine the dimensioning of the simulated network.

2.2. The Network Communication System KPIs

The mobile network data services are penetrating mobile markets rapidly. The mobile industry relies heavily on data service to replace the traditional voice services with the evolution of the wireless technology and market. “A reliable packet service network is critical to the mobile operators to maintain their core competence in data service market. Furthermore, mobile operators need to develop effective operational models to manage the varying mix of voice, data and video traffic on a single network. The application of statistical models could prove to be an effective approach, like *KPI* the an multivariate statistical analysis to monitored from telecommunication network entities to measure the QoS and to analyze the alarms from technologies in different case and kind of alarms generated by a site in an controller (BSC/RNC)” (In et al., 2012).

The telecommunication services for *Public Safety & Security* (*PSS*) organizations are concerned, *QoS* requirements are highly demanding and their compliance is critical owing to the type of users of these services. A set of *KPIs* that could be used to assess the QoS levels, it can be provided by different kind of KPIs, that we can analyze the network that are commonly used to provide service to the clients in different tool to help the engineers to planning and require the better improving and performance in networks, using different KPIs that are widely used by GSM UMTS and LTE carriers with the aim of evaluating the network performance and the QoS delivered to users” (Luis Delgado & Santiago, 2013).

2.2.1. The GSM Network Communication System KPI

The customer satisfaction is critical to gain a sustainable competitive edge in the market, in communication networks, as the customer's satisfaction with the service is directly dependent on the quality and the performance of the network, measurements of network performance and quality of service QoS assessments are crucial.

The network operators should survey the performance of their networks and measure quality parameters on a regular basis as customers' needs and satisfaction are presumably the main market driver, and especially in wide-area service networks such as cellular communications networks. “Generally, network optimization engineers exert efforts to increase the quality and capacity of operational networks, and to develop and deploy new services to meet customer demands and to guarantee customer satisfaction. KPIs are universally accepted parameters of cellular networks that engineers need to survey and keep within some species threshold values in order to meet the QoS criteria required by both competent authorities and customers” (Kadioğlu, Dalveren, & Ali, 2015).

The QoS can be described as the ability of a network to provide a service at an assured service level, that can be measured by either the network operator itself or by an independent or regulatory organization. And “QoS is very critical in cellular communication networks, including *2G* and *3G* systems. As 2G networks were unable to provide better and faster data services, 3G system have been deployed to provide a variety of data services such as internet browsing, e-mails, video telephony, and video streaming (dense data needs such as YouTube or Instagram)” (Kadioğlu et al., 2015).

The” currently, both 2G and 3G cellular networks have become operational in most countries, almost all current operational cellular networks support both *circuit-switched* (*CS*) and *PS* services, and *QoS* assessment of CS and PS services should be evaluated separately” (Kadioğlu et al., 2015). The QoS assessment is based on QoS parameters, which can be given with a layered structure like as:

- the first layer represents network availability as the QoS from the service provider's point of view;

- the second layer represents network access as the basic requirement from the user's point of view;
- the third layer represents various QoS aspects, including service access, service integrity, and service retainability;
- the fourth layer represents different services whose outcomes are the QoS parameters; and, finally,
- the last layer represents KPIs of each service of the fourth layer.

The "KPIs constitute the bottom layer, and benchmarking is mostly conducted with standard KPIs that have been used for many years. In drive tests, KPIs were obtained for each network operator by measurements performed on specified routes" (Kadioğlu et al., 2015). Some of the KPIs and their descriptions are, as they are used in benchmarking, listed in Table 2.

Table 2 - KPIs and their descriptions for CS and PS services (Engineering 2015)[10].

Service	KPI	Description
CS (Voice)	Call setup success rate (CSSR) (%)	The ratio of successful call setups to call attempts
	Call setup time (CST) (s)	Duration to completing address information
	Dropped call rate (DCR) (%)	The ratio of number of dropped calls to successful calls
	Speech quality (PESQ)	Quality of speech as perceived by users
	Received signal level (RxL) (dBm)	Received signal power at the input of the mobile device
PS (Data)	Attach success rate (ASR) (%)	Probability that a subscriber can attach to the net-work
	Attach time setup (ATS) (s)	Time duration taken to attach to the network
	Packet data protocol (PDP) context activation success rate (CASR)	Probability that subscriber can activate a PDP con-text (%)
	PDP context service access success rate (SACR) (%)	Probability that a subscriber accesses the service successfully
	Service session success rate (SSSR) (%)	Probability of initiating the service by the subscriber
	FTP data throughput (FTP DL) (kbps)	Average data rate that can be achieved

[10] Table taken from the: https://www.researchgate.net/search.Search.html?type=publication&query=The%20%20GSM%20%20KPIs

The GSM network usually called as 'cellular network' (as the whole coverage area is divided into different cells and sectors) is comprised of a mobile Station (MS) which is connected to the *Base Transceiver Station* (*BTS*) via air interface. In "addition to other hardware, BTS contains the equipment called *Transceiver* (*TRX*), which is responsible for the transmission and reception of several *radio frequency* (*RF*) signals to/from the end user. BTS is then connected to the *base station controller* (*BSC*) via abis interface. BSC usually handles radio resource management and handovers of the calls from a BTS (cells/sector) to the other BTS (cells/sector) in it. BSC is then connected to Mobile Switching Centre (MSC). Before GSM network installation, RF network planning (RNP) teams plan the BTS sites to cover a certain specific area keeping in view the terrain and population. Moreover, marketing teams also help RNP teams to predict population and user traffic estimation in the days to come. RNP teams visit the areas to be covered and prepare technical site survey reports (TSSR). RNP teams use specific enterprise tools such as MapInfo, ASSETT etc. to plan the sites having different frequency and miscellaneous parameter allocations" (Kumar, 2015).

The "GSM network performance and QoS evaluation are the most important steps for the mobile operators as the revenue and customer satisfaction is directly related to network performance and quality. *Radio frequency network optimization* (*RNO*) teams play a very significant and vital role in optimizing an operational network to meet the ever-increasing demands from the end users" (Kumar, 2015).

Usually the following tasks are assigned to RNO teams like as:

- To improve the existing network coverage and capacity.
- To improve the offered service quality for fulfilment of customer demands.
- To maintain the KPIs under pre-defined threshold.
- To sustain the QoS criteria being imposed by country's regulatory authority.
- To standardize and benchmark the network performance with that of competitor's network to attract more customers; keeping a balance between cost and quality.
- To effectively reuse the available bandwidth and frequency carriers in order to avoid internal interference and service degradation.

GSM Network service providers analyse the network performance and evaluate service quality indicators. These indicators can be used for the following mentioned purposes like as:

- To identify and locate BSS (hardware) occasional faults to ensure physical resource availability.
- To help RF tuning teams to analyse the radio situation, detect radio network problems in one or more BTS and finally devise a way to optimize the network and adopt corrective actions like new frequency allocations, antenna tilt adjustment, and parameter modification in OMCR database *etc*.
- To monitor system behaviour and variance in terms of traffic load, congestion, successful attempts etc.
- To predict the upcoming traffic evolution and network expansions as per increasing number of mobile users.
- To benchmark network with another competitor's network to attract more users at the cost of better quality.

2.2.2. The UMTS Network Communication System KPI

The *UMTS* architecture and *packet switched (PS)* network applies multivariate statistical analysis to KPI monitored from network entities, in UMTS PS network to guide the long-term capacity planning for the network. This approach could be helpful to mobile operators in operating and maintaining in packet switched domain of 3G UMTS networks serves for all data related services for the mobile subscribers.

Nowadays people have a certain expectation for their experience of mobile data services that the mobile wireless environment has not fully met since the speed at which they can access their packet switching services has been limited. This makes "the mobile operators realize that if they are to succeed in today's wireless communications landscape, they must address the quality of service for their packet service users. Simply adding more bandwidth to accommodate increased packet switching traffic is an expensive alternative" (In et al., 2012). With this issue makes the mobile operators are faced with the issue of how to do more with less? And the best answer can be in a new capital investment in expanding the network infrastructure to ensure the network is operating optimally.

For a network administrator, the traditional network operation and maintenance (O&M) pattern follows a cycle like as:

- If a problem is encountered, "from hardware or software failures to network congestions, the technician issues a ticket, debugs the network, and fix the problem and operation continues" (In et al., 2012).
- If this "mode of operation may be adequate for ensuring timely and quality service of data traffic in a short run. However, it does not help mobile operators effectively and actively forecast and prevent potential problems in packet switched network in advance" (In et al., 2012).

The "UMTS PS network is a typical data network in which data traffic, particularly with streaming media services, is live, extremely time sensitive to delay, latency and jitter, non-tolerant of congestion" (In et al., 2012). For example, a small minority of packet service subscribers running FTP, streaming video or peer-to-peer (P2P) file sharing applications can generate enough traffic to congest UMTS PS

networks and impact the majority of subscribers using interactive Web browsing and E-mail applications.

In the past network operation and maintenance was focused more on monitoring the entire throughput. The “UMTS PS model for service monitoring shall be capable of monitoring and capturing the necessary KPI data at the service level in addition to the network level. In the model, distinct types of service packet enter PS core domain via Iu-PS interface, the entry port of SGSN. After the encapsulated tunneling transport between SGSN and GGSN, the packets are delivered out to external network via the exit: Gi interface in GGSN. Hence the data monitoring starts from interface Iu-PS, the entry port of SGSN, and ends in interface Gi which is the exit of GGSN” (In et al., 2012).

The “monitored KPIs for the model include two types of parameters: QoS/performance parameters and service parameters, the former of which includes delay, jitter, packet loss, throughput, and utilization; while the latter includes the throughput of all types of services going through SGSN and GGSN” (In et al., 2012). *Figure 12* depicts the service model of UMTS PS network for performance monitoring, and different from traditional instant network monitoring, the UMTS PS model for service monitoring shall achieve like as:

- A long run view of the PS service the user is experiencing;
- Service-level quality and performance metrics which are affected by the traffic as well as vendors equipment (SGSN and GGSN);
- Correlation of fault and performance data captured over a long period to identify the potential service affecting outages;
- Consolidated utilization and performance data that can be applied for future network expansion planning.

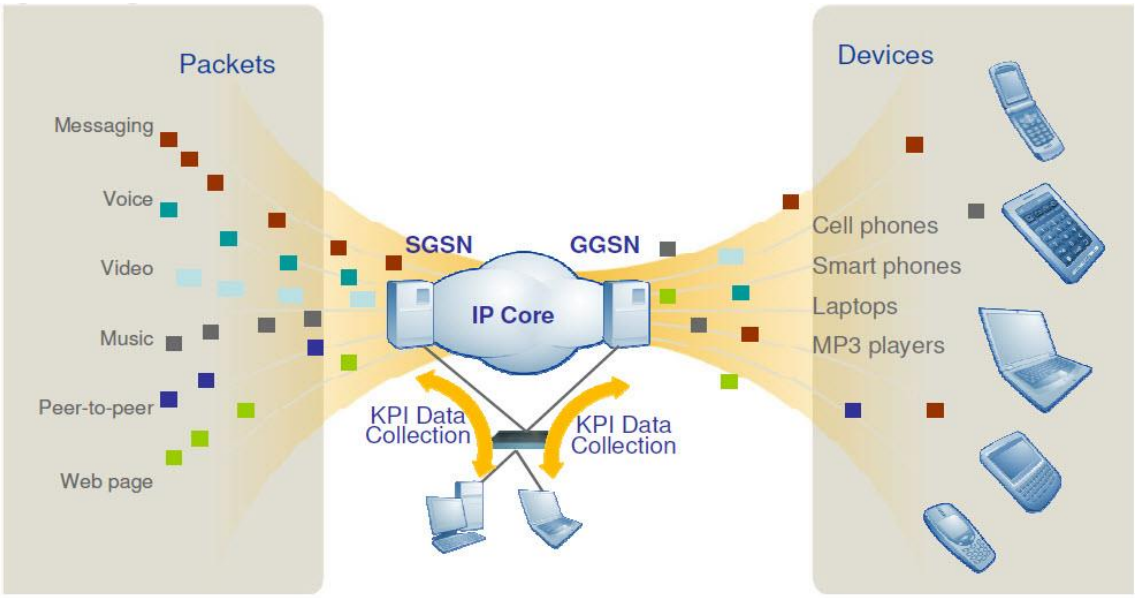

Figure 12 - UMTS PS Model of Service Monitoring (In, 2012)[11]

The statistical models can be used in modeling and developing operation policies for the *UMTS* network environment as shown in *Figure 13* as a trial UMTS PS network. The "system as highlighted is composed of a SGSN which connects with radio network via Iu-PS interface and a GGSN which accesses Internet and Intranet of Enterprise 1. Firewall and *Network Address Translation* (*NAT*) are built between *UMTS PS* network and external networks" (In et al., 2012).

The radio network domain consists of a Node-B (Base station) and a RNC. The network administrator monitors the network traffic through management station with authorities to access the *Network Entities* (*NE*) of *UMTS PS* network. The objective of this experiment is to monitor the throughput in interface Gi (Eth1:100) as it leaves GGSN.

[11] Image taken from the: https://arxiv.org/ftp/arxiv/papers/1003/1003.5438.pdf

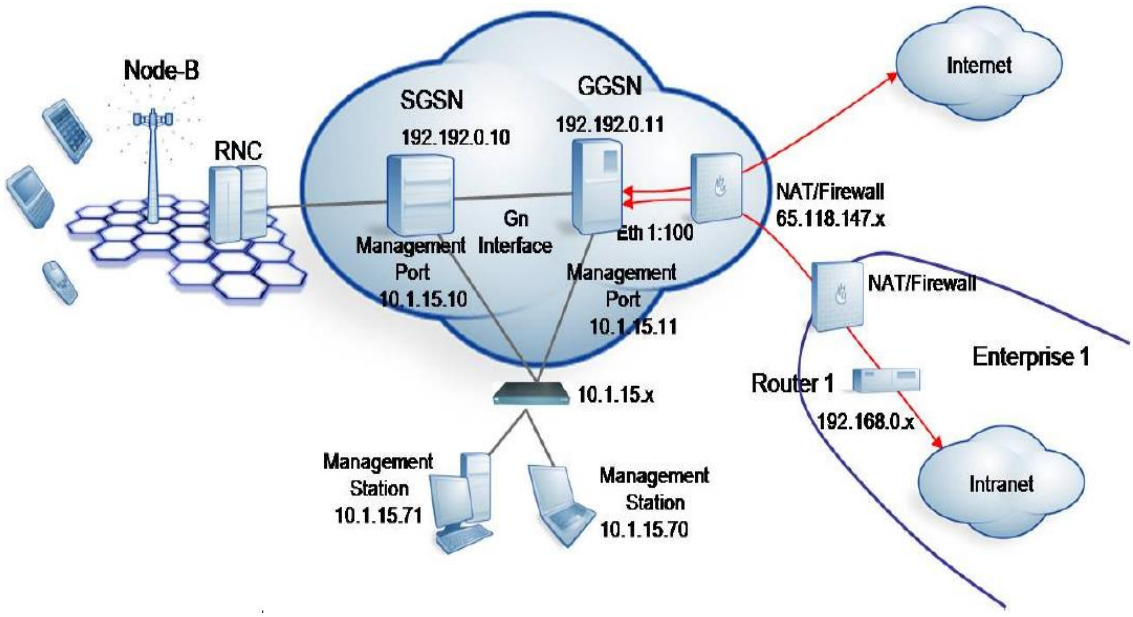

Figure 13 - Network topology of trail UMTS PS network (In, 2012)[12]

The services are randomly triggered by a service/call generator tool in lieu of RNC, Node B and wireless terminals. The "tool stores large quantities of historical traffic samples from a certain mobile operator A's network environment. Hence the tool in our case is actually a substitution of radio domain to simulate the real network environment of the mobile operator A. The simulated traffic generated by the tool is stochastically delivered into SGSN via Iu-PS interface and further transported through packet switched domain" (In et al., 2012).

The "whole simulation process is no difference with a real network environment from traffic monitoring aspect. The performance parameters and service parameters are monitored as outputs based on the simulated traffic of services generated by the service generator. If this model is applied in a real environment, the monitored data will be the monitoring result based on the real traffic generated and delivered from radio domain" (In et al., 2012). Five key performance indicators (KPI) are recorded as the network QoS parameters like as:

- Latency, GGSN average loading (Utilization), throughput in Eth1:100, packet loss in interface Gn (192.168.0.11) between GGSN and SGSN, and

[12] Image taken from the: https://arxiv.org/ftp/arxiv/papers/1003/1003.5438.pdf

packet loss in interface Gi (Eth1:100 IP address: 192.168.0.12) between GGSN and external network.

- The management station collects the KPI data in 20 continuous sample periods (1 hour as 1 sample period). The sample data round up to fifth places of decimals after unit conversion from per hour to per second are recorded in Table 3.

Table 3 - KPI data network (In, 2012)[13]

Sample Period	GGSN Utilization (%)	Gn interface Packet loss (Packet/s)	Gi interface Packet loss (Packet/s)	Latency (Second)	Throughput in Gi interface(Eth1:100) (Mbps)
Hour 1	1	0	0	0.00204	2.442508
Hr 2	1	0	0	0.00213	3.348526
Hr 3	3	0.00028 0	0	0.00238	87.952500
Hr 4	3	0	0	0.00243	99.157604
Hr 5	5	0	0	0.00294	216.021441
Hr 6	6	0	0.00028	0.00277	238.313785
Hr 7	2	0	0	0.00208	28.812852
Hr 8	2	0	0	0.00213	48.393216
Hr 9	3	0.00333	0.00056	0.00217	65.983333
Hr 10	2	0	0	0.00208	29.313644
Hr 11	2	0	0.0025	0.00213	57.543637
Hr 12	1	0	0	0.00200	2.781329
Hr 13	1	0	0	0.00200	2.660693
Hr 14	1	0	0	0.00200	2.667828
Hr 15	1	0	0	0.00200	3.030091
Hr 16	1	0	0	0.00200	2.578499
Hr 17	1	0	0	0.00204	2.371938
Hr 18	1	0	0	0.00213	2.370775
Hr 19	1	0	0	0.00238	2.373311
Hr 20	1	0	0	0.00243	2.369829

[13] Image taken from the: https://arxiv.org/ftp/arxiv/papers/1003/1003.5438.pdf

2.2.3. The LTE Network Communication System KPI

The LTE Like other cellular technologies requires measurement collection which is called “drive testing” in the earliest phases of deployment as well as during the network’s life cycle, the “main benefit of drive testing is to Obtain Key Performance Indicators (KPIs) such as Signal Strength, Signal Quality and all needed data related to the coverage, and these measurements are usually obtained by a professional tool with special software and license. Nowadays, LTE, a 4G high speed data connection for mobile devices, has divergent merits to ensure customer satisfaction. For instance, the LTE aims at extending capacity, getting peak data rates, and reducing latency to ensure the QoS” (Al-shamisi, Al-shamisi, Kostanic, & Zec, 2018).

When making a call, the UE moves from one base station to another. To maintain a steady connection between the base station and the UE, the user equipment has to perform handover for cell selection or re-selection. This “task can be achieved through measuring the KPIs such as *Reference Signal Received Power* (*RSRP*), *Receiver Signal Strength Indicator* (*RSSI*), and the *Reference Signal Received Quality* (*RSRQ*). These indicators are ranked and referred to as the coverage parameters. RSRP, also known as, received power by receiver (UE) from reference signal resource elements over desired bandwidth and it is essentially used for making a selection, reselection and reliable handover for a cell when a user equipment moves from a cell to another cell” (Al-shamisi et al., 2018).

The RSRP can be calculated using the following formal like as:

$$RSRP[dBm] = RSSI\ [dBm] - 10 \log(12N);$$

Where, N is the number of Resource Blocks (for 10 MHz, N=50).

The KPI can be determined by developing running application on any smart phones. It is an effective method to find key performance indicators with end-user experience and network performance which help the researchers to develop solution for network issues and Mobile Network Operators for improving their network arrangement and to abstain from using costly, tedious devices to achieve the required parameters. In a typical “troubleshooting process, the optimization expert analyzes KPIs and then

proposes a new *Radio Resource Management* (*RRM*) parameter which is applied to the problematic BS. The BS operates with the new parameter during a period long enough, typically a day, to have statistically significant results that allow to assess the BS performance. This optimization process is reiterated during several days, typically between one to two weeks" (Tiwana, Altman, & Sayrac, 2010).

The difficulty for devising automated healing algorithms are twofold. "First, optimization heuristics often require hundreds of iterations and more time to converge. Second, measured counters and KPIs are inherently noisy. And noise can originate from limited measurement accuracy, but also from traffic fluctuations, varying propagation conditions etc. The effect of RRM parameter modification on KPIs can be masked partially by unobserved effects thus introducing uncertainty in the relation between KPIs and RRM parameters" (Tiwana et al., 2010).

The "Optimization block calculates the optimal RRM value using the current statistical model. It minimizes a cost function of certain KPIs under constraints imposed on other KPIs. The automated healing model assumes that the KPIs are well behaved functions, namely they are not multi-modal functions of the RRM parameter. This assumption allows to capture the functional form of the KPIs using regression techniques. The automated healing process is iterative. At each new iteration, on the average, the model precision improves and is used by the optimization block to find a better value for the RRM parameter. In the following, the Statistical Learning and the Optimization blocks are described in detail" (Tiwana et al., 2010).

Since the "LTE deployment were carried out in urban and sub-urban initially, the equipment vendors who were contributing actively in the *LSTI group*[14] deployed test sites in the major cities that simulated the exact conditions of the operators. These tests were carried with the 2x2 MIMO antenna configurations using slim-line cross-polarized multiband antennas that are used in 3G commercial deployments" (Ontents, 2015).

As the tradition, a wide range of *KPIs* were used by the mobile network operators and equipment vendors to analyse the network performance and quality to ensure that

[14] LSTI group: is an open group founded by the various telecommunication industry leaders that comprised of vendors and operators who are working together to speed up the development of LTE/SAE.

operator's targets are met. The "maintenance of KPIs has always been a contentious issue between the operators and the equipment vendors. KPIs are always selected from the bottom up but often not coordinated properly, and this results in an ambiguous calculations of network performances. Sometimes, at the behest of the network operators, equipment vendors invest considerable energy and time to improve selected KPIs, but at the cost of other KPIs. KPI selection is another important activity for network operators. If KPIs are not selected properly, then it would have least impact in monitoring the network performance and they will not provide factual condition of the network" (Ontents, 2015).

The Network operators "needs to be assured by the equipment vendors, that the KPIs defined for the network should reflect the tangible user behavior and the user experience. For example, a KPI on LTE radio bearer can be dropped when analyzing LTE device, since the device is not transmitting the data. These type KPIs does not offer precise understanding of the subscriber experience, since the sessions can be established quickly when required and delays goes unobserved by the subscribers" (Ontents, 2015).

The mobile phone communication like Smartphone behavior, adds complexity to the performance measurement. "Generally, the traffic generated by these devices is different compared to the traffic generated by the USB dongle. The behavior of the devices in the network changes with the new software upgrade, new model of devices introduced in the market and with the introduction of new apps, and this will affect the interpretation of KPIs. The KPI management is difficult in a single technology environment. In a PLMN, which encompasses different flavors of technologies such as 2G, 3G and 4G, the intensity of the complexities increases significantly and the resilience level of the KPIs as the true compilation of ground realities should be shored up" (Ontents, 2015).

At this juncture, an analogy is worth comparing here. The electrical standards of different countries are different and similarly, measurement of the network performances varies with the vendors. "But as a single metric system, the KPI measurement and the definition by different vendors should be harmonized with the standards laid down by the standards institutes such as ITU and ETSI etc. In general, the KPI management framework should consist of metrics complying with the standards

institutes such as ITU and ETSI. The parameter settings of the elements should comply with the standards laid down by these institutes, only the relevant KPIs related to the user's experience should be included, the KPI measurement procedure should be explained adequately, KPI validation tests should be carried out to verify whether the defined KPIs meets the operator's objective" (Ericsson, 2011).

Handling of the spectrum is another major issue faced by the operators. "Since frequencies are scarce resources and providing high data rates to the subscribers is very difficult without the management of these resource. Hence, a new technique of carrier aggregation (CA) is introduced in LTE-A. CA is one of the important features of LTE-A that was standardized by 3GPP recently in Release- 10. This feature is designed to satisfy the IMT advanced requirements. In this feature, the eNodeB (eNB) can combine multiple spectrum bands to support high data rates in both uplink and downlink. Each carrier handles the traffics separately that are subdivided and then transmitted using physical layer resources of the carrier" (Ontents, 2015).

This requires "a separate link level mechanism like *hybrid automatic repeat request* (*HARQ*) and control signaling for each carrier component. The backward compatibility of the LTE-A with LTE is very important. The LTE device that does not support LTE-A, will use one of the band and the handsets that support CA, will use multiple spectrum bands to send and receive data" (Ontents, 2015).

There are two types of CA configurations used in LTE-A and they are continuous CA and non-continuous CA.

- Continuous CA in "this mode, the spectrum bands which contain 20MHz should be arranged adjacent so that they can be aggregated to create 40 MHz band as a single spectrum" (Ontents, 2015).
- Non-continuous CA in "this mode, the aggregated carriers can be non-contiguous and can be from different bands *e.g.*, an aggregation can be formed between two frequency bands such as 800 MHz and 2.6 GHz which are in different location of the spectrum bands. The channel characteristics such as path loss, building penetration loss and Doppler shift will have different

behavior in different frequency bands and these variations can be minimized in the scheduler through radio resource management (RRM)" (Ontents, 2015).

The "ITU-T along with the ETSI (ETSI, 2009) (3GPP, 2009) has prescribed the standardizations that needs to be adhered to provide better QoS for the subscribers. Adherence to these standards provides better QoS and provides excellent service accessibility, retainability, mobility and integrity" (Ontents, 2015).

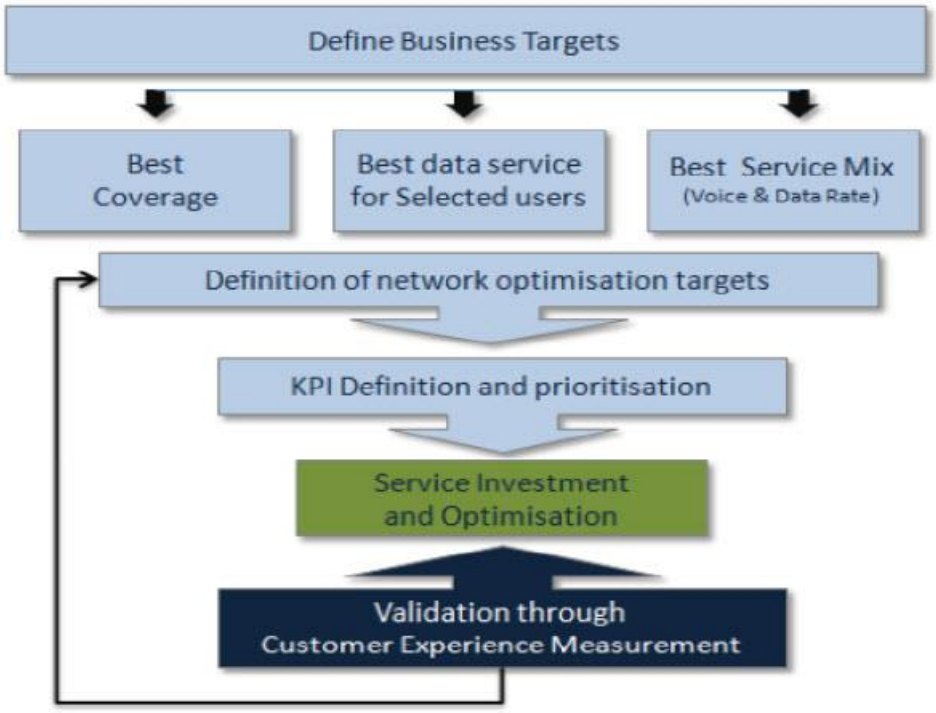

Figure14 - ITU recommended KPI methodology Internet (Ontents, 2015)[15]

The Figure 14 illustrates the KPI methodology that adheres to the ITU recommendation to measure subscriber experience and network quality. In general, the adeptness of a network can be demonstrated in a lab which will not have any semblance to the live network. "These demonstrations are usually carried out with high end user terminals, with co-located *evolved packet core* (*EPC*) with eNB, with well-defined interfaces etc. But this condition does not exist in the real-time network. In real time network, the performance and capacity go in tandem. Both are very important parameters in a real-time network. Hence, a trade-off between these parameters should be considered. These conditions must be considered carefully while designing a test bed

[15] Imagem retirada do site: https://opus.lib.uts.edu.au/bitstream/10453/38964/1/2015%20Ram%20INTEROPERABILITY%20AND%20QUALITY%20ASSURANCE%20Interop%207515ijwmn05.pdf

to design reliable KPIs to measure the user experience. Hence, the tests should be conducted using commercial available terminals, standard network settings, and transparent calculations of KPIs" (Ontents, 2015).

To obtain scalability, reducing energy consumption and achieving better network performance and to plays a vital role in large multi-networks, is clustering where the cluster heads (CH) aggregates the data and reduces the traffic significantly. This model works in two ways 1) periodic selection of CH and 2) assignment of nodes to the clusters. A suitable strategy must be employed to select the appropriate KPIs to analyse the clustering of the network.

The vendors and operators "should work in tandem on these KPIs and there should be a clear understanding between them about what KPIs are required and how it is designed before the actual start of the testing. In fact, it would be better if these types of agreements are reached before the start of official the contract" (Ontents, 2015). The Table 4 summarize the broad KPI frame work commonly used KPIs design by the vendors.

Table 4 - KPI frame work (Ontents, 2015)[16]

CATEGORY	DESCRIPTION
Accessibility	This type of KPIs gives an idea about the session setup and session success rate in a well-defined condition.
Service Retention	This category gives an idea about the service continuity and it can be used to calculate whether abnormal failures occur such as dropped calls.
Service Impairments	This will help to check whether the obtained service faces any impairment because of uplink or downlink throughput or packet loss.
Mobility	This section covers various handover

[16] Imagem retirada do site: https://opus.lib.uts.edu.au/bitstream/10453/38964/1/2015%20Ram%20INTEROPERABILITY%20AND%20QUALITY%20ASSURANCE%20Interop%207515ijwmn05.pdf

Management	types both success and failure conditions

The Table 5 show us the typically summarizes of the KPI framework for LTE network verification. In this table, each KPI must be tested under various conditions such as controlled environment, during site acceptance and during the service operation stage. The "content of the table may vary depending on the operators. The table must be designed in consultation with the operators and each term in the table must be in accordance with the operator's knowledge and plan. Some KPIs in this table, such as throughput varies both in uplink and downlink and depending on the location, user behavior etc. So, the metrics of the throughput performance indicators are not marked as not KPIs but they are the objectives that need to be measured to monitor the network capacity" (Ontents, 2015).

The "KPI reports on retainability, accessibility, traffic and mobility with handover (HO) attempts were generated based on the previously discussed strategy and in consultation with the operators. The minute details of all the KPIs are not provided in this section. Only a broad KPI analysis is made. The details of each KPI definition and representation are left to the users design depending on the circumstances and the network design and planning" (Ontents, 2015).

Table 5 - KPI framework for LTE network verification(Ontents, 2015)[17]

KPI	**LAB**	**SITE ROLL OUT**	**CLUSTER**
Cell availability	Yes		Yes
Session setup success rate	Yes		Yes
Abnormal session release rate	Yes		Yes
RTT	Yes	Yes	Yes
RTT packet loss	Yes	Yes	Yes
Uplink packet loss	Yes		
Downlink packet loss	Yes		
Throughout (uplink and downlink)	PI	PI	PI

[17] Imagem retirada do site: https://opus.lib.uts.edu.au/bitstream/10453/38964/1/2015%20Ram%20INTEROPERABILITY%20AND%20QUALITY%20ASSURANCE%20Interop%207515ijwmn05.pdf

Handover success rate		Yes	Yes
Voice-session setup time	Yes		
Voice-session setup success	Yes		
Voice-session abnormal failure rate	Yes		

2.3. The KPIs Analysis

The "demand of wireless communication has been on the increase from generation to generation. Most common ones are the data and/or voice communication that includes Infrared, Bluetooth, Mobile Ad hoc Networks (MANETs), Vehicular Ad hoc Networks (VANETs), Voice Over Internet Protocol (VoIP), Global System for Mobile Communication (GSM), etc.". (Musa, 2017).

The "GSM is the most popular among them because it is easy to acquire and maintain, has clarity of voice communication and ease of data communication among others. However, the effective performance of the GSM is greatly challenged by the added features of data communications (*i.e*. General Packet Radio Service (GPRS)) on the same system though, third Generation (3G) Technology has greatly reduced this challenge to the barest" (Musa, 2017). Another degrading factor facing GSM power throughput is the traffic congestion that takes multifarious dimensions. Therefore, this paper aimed at identifying some of the causes of this congestion as they affect the service performance of the mobile network a case study of telecommunication providers area and operators.

This is "an analysis of traffic congestion in the Mobile Network of Telecommunication (*MTN*) providers area and operators, due to unplanned event with a view to reducing its effect. Drive and Pulled data test methods where adopted for the network performance during peak and off-peak periods. The Drive Test gave a 20% and 10% deviation from the recommended KPIs set by MTN during peak and off-peak hours respectively, while the Data Pulled test during an unplanned public event indicates that the cells near the scene of the event experienced high congestion level with a 32% (PCong), 3.5-6% (Pdrop), 76.59% (TCH availability), and 96.18% (SDCCH) which is a great deviation from the MTN acceptable KPIs of <5%, <2% , >99% and >98% respectively"(Musa, 2017).

The main goal of this section is about the analysis of both hardware and software solutions that will help minimized these distributed congestion challenges within the network system in KPIs, that served as the gauge to those parameters of the network that determine its performance. The system will be at its optimum when these

performance parameters are all measured to be operating at the KPIs. This research considers the following as key performance parameters of the system like as:

- Paging Success Rate
- Immediate Assignment Success Rate
- Random Access Success Rate
- TCH Assignment Success Rate
- Call Drop Rate
- Handover Success Rate

The "KPIs as previously stated may have an International Standard as such mobile operators may have their own reference point due to their peculiarities and the condition under which they are operating"(Musa, 2017).

Table 6 - KPI for MNT Operator (Musa, 2017)[18]

Metric	**KPI**
Percentage Congestion (Pcong)	<5%
Percentage Drop (Pdrop)	<2%
Erlang	According to site design
Traffic Channel (TCH) Availability	>99%
Percentage Control Congestion (PCCong)	<1%
PBADICM	<2%
Percentage Traffic (PTFail)	<5%
Percentage Setup (PSFail)	<5%
Percentage Control Fail (PCFail)	<5%
Handover (HO) Success Rate	>95%
Call Setup Success Rate CSSR	>95%

The one of others way to analyse the KPI is to use the two basic methods in data collection, these are:

- Drive Test

[18] Image taken from the: https://www.researchgate.net/publication/320083518_Performance_Appraisal_of_Mobile_Telecommunication_Network_in_Dutse_Jigawa_State

- Record tracking from the network stack counters.

The traffic congestion audit of MTN cells located was therefore conducted via the drive test and record tracking methods details and results.

The "drive test is a means of data collection on moving vehicle. This type of test is done regardless of the technology involved e.g. *GSM, CDMA, UMTS*, and *LTE* etc. the analysis of the drive test data is the inhibiting factor toward evaluating a network and in return may make some changes in an effort to optimizing the entire system" (Musa, 2017). The following equipment are needed to carry out a successful drive test like as:

- Laptop Computer
- Data Collection Software (e.g. TEMS 9.0 for this case)
- Dongle Key (Serve as security for unlocking the software inform of flash memory)
- Mobile Phone (at least one mobile phone)
- A Global Positioning System (GPS) worldwide navigation system that uses information received from orbiting satellites.
- A Scanner (Optional).

And basically, there are numerous types/reasons for which a drive test was conducted among others are:

- Performance Analysis
- Integration of new sites and change parameters of existing ones
- Marketing
- Benchmarking

The "most popular among these are the *Performance Analysis* (for an individual operator) and the *Benchmarking* (Compares between two or more operators). Test for performance analysis is the most common, and usually made in areas/sites of interest.
Drive test for data collection and/or analysis allows test data to be collected while moving. The data can be viewed or analysed in real time allowing a view of network

performance on the field. Data from all units are grouped by collection software and stored" (Musa, 2017).

The "GPS is meant to collect the data latitude and longitude of every point of measurement like time, speed etc. In other word, it also helps in locating a predefined route. The mobile station (MS) is meant for call initiation at regular interval via a predefined frequency so that data like signal strength, best cell handover success, etc. can be recorded" (Musa, 2017).

The "company is transitioning from the current phase of gadgets to dashboard-based information presentation. This is in correlation to a more generic way of working, which enables teams to create their own independent dashboards, to monitor their specific areas of interest. Currently there is a need to visualize the status of a test telecommunication network at Ericsson. The reason for this is to be able to validate their solutions, innovations, and experiments in a customer-like environment, thus shortening the feedback-loop considerably, e.g. while testing features on the network" (Larsson, 2015).

The *status* of this network that needs to be visualized in this case is a broad term but can be reduced to the concept of *data regarding current activities in the network*. These data can for example be like as:

- The number of users that are currently using the network.
- How much bandwidth that is available per user / in total.
- How much CPU load the current activities are applying on a node.
- How many failed connections that have occurred or how much data that has been dropped due to errors.

Dashboards are one way to visualize the status of a network. It functions as an overview of measurements, providing a simple summary. The "company works according to lean and agile paradigm, it has agile teams that have a holistic responsibility for the features they develop and test. Some of the teams started to develop dashboards by themselves in order to get an overview of the features that they were responsible for. It became the task of the metrics team, a team in the company concerned with measurements and developing in-house visualization products, to turn

these dashboards into a generic product for all teams to use and benefit from. They also had the challenge of creating a visualization of the test network, which would give other teams than the test team the possibility to view the status of it. Although in order for the metrics team to develop and maintain a lager set of dashboards; a need for a generic solution became apparent" (Larsson, 2015).

The "measurement process has the purpose of collecting, analyzing and reporting data, with the intention of managing and demonstrating the quality of processes and products. Implementing measurement systems enables a company to improve in a more efficient way, since it has the capability to measure its performance in key areas" (Larsson, 2015). A measure in itself is not a usable measurement; it should have a purpose and be something upon which it's possible to base actions (e.g. measured productivity in a company).

The "teams needed to be able to configure visualizations that were relevant to the specific team's objectives, as well as being relevant to the whole team and not only to the leader. At this point in time, dashboards were chosen as an applicable solution. There were many different dashboards and information gateways present at the company, developed for specific purposes" (Larsson, 2015).

These display KPI/PI values that are of relevance to teams (see Figure 15); however, this information did not contain everything that was needed to be useful to diagnose the network. Therefore, the company wished to extend their visualization capability by providing dashboards to monitor the current *status* of the network. The *status*, as defined by the company is metrics and trends regarding how many users are currently connected to the network, how much traffic is flowing through the nodes, how many failures have occurred, etc.

The metrics team also had a need of an updated manual and instructions to facilitate further work with dashboards.

Figure 15- Snapshot of a type of network status visualization (Larsson 2015)[19]

[19] Image taken from the: https://gupea.ub.gu.se/bitstream/2077/39976/1/gupea_2077_39976_1.pdf

2.3.1. The Netact KPI Tool

In recent years, mobile technology has taken huge steps in equipment as well as network side development. This has made possible to develop new type of mobile services and applications. Therefore, "the requirements for data rates have been increasing rapidly and this has created a need for even more efficient network monitoring and management tools. The Nokia's solution for network management develop the dimensioning model based on operator data called by NetAct operations performance testing management system" (Engineering, 2015).

According to the Nokia NetAct™ operating documentation, "NetAct is a network management system for multi-vendor and multi-technology networks; in other words, it is an *operations support system* (*OSS*). In practice NetAct combines the management of overall network operations, individual network elements and services. It`s also a modular system, where customer can activate features based on his or her needs. NetAct modules can be divided to four major categories: *configuration*, fault management, performance and security management" (Engineering, 2015). NetAct is used with a graphical user interface and its start page can be seen in Figure 16.

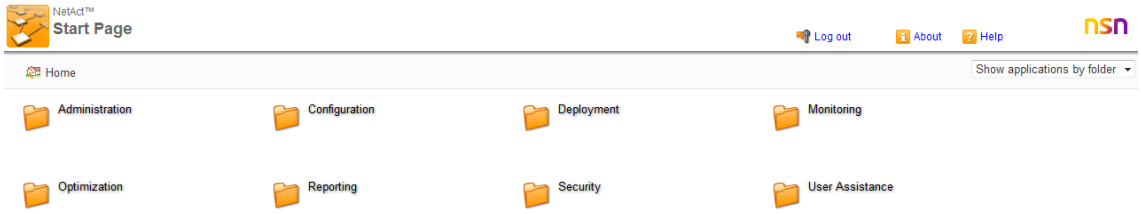

Figure16 - NetAct Start Page (Engineering 2015)[20]

The Start page provides a central access point to NetAct applications and from there the user can navigate further to configure and manage the network and its elements.

The *Configuration Management* (*CM*) is to "configure and manage the radio and core networks where there are five major applications and their aim is to provide automated tools for managing network configuration data, provisioning changes, and correcting inconsistencies" (Engineering, 2015).

[20] Image taken from the: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

- CM Analyzer for “checking the consistency of the different networks, network elements and parameter configurations handled by the system” (Engineering, 2015).
- CM Editor for managing network elements and configurations.
- CM Operations Manager for scheduling different “operations supported by the system. CM Operations Manager also provides real-time feedback on the pro-gress of the operations and history information on the executed operations” (Engineering, 2015).
- CM Reference for managing reference configurations that represent the planned network configurations.
- SON Scheduler for “viewing and configuring operations in the LTE Flexi Multi-radio base transceiver station (BTS) elements. These operations include auto-connection and auto-configuration features both for LTE and WCDMA” (Engineering, 2015).

The one of main application of Netact use to different technologies it`s main Windows of CM EDITOR shows in figure 17, where the user`s editing the GSM, UMTS and LTE parameters in multiradio base station (BCF, RNC and MRBTS).

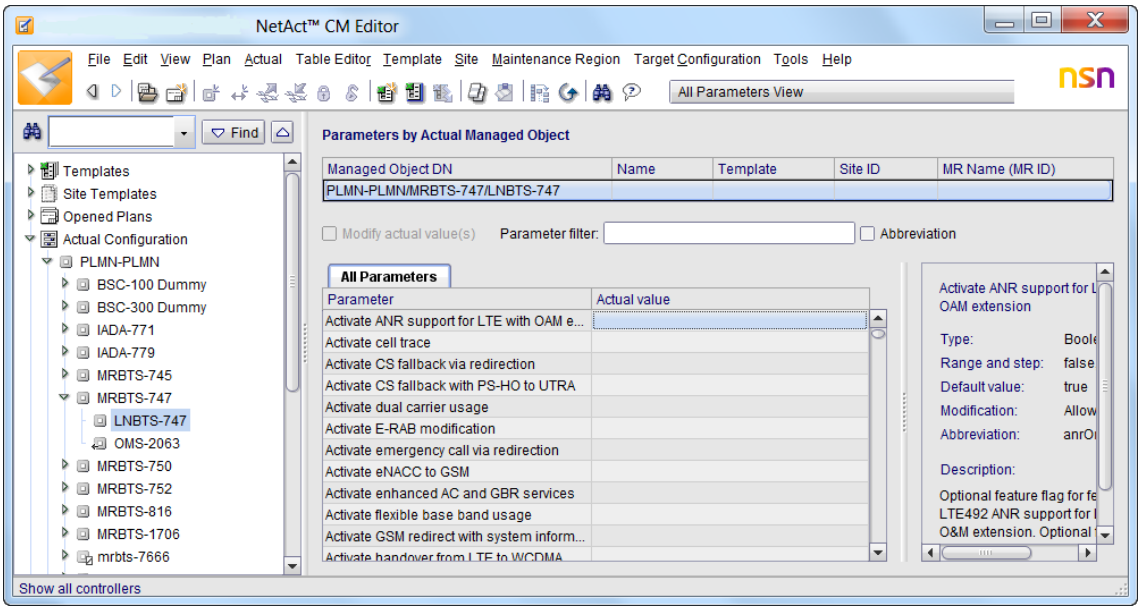

Figure17 - NetAct CM Editor (Engineering 2015)[21]

The *Performance Management* (*PM*) is a "set of applications for processing, analyzing and visualizing performance data coming from different sources. More specifically, PM is multi-vendor capable and collects data from the entire network that consists of network elements. Multivendor capable means that PM is capable to handle seamlessly network elements manufactured by different manufacturers." (Engineering, 2015).

The aim of any PM activity is to collect data to support the following activities like as:

- Verifying the physical and logical configuration of the telecommunications network
- Monitoring continuously how the network functions
- Localizing potential problems as early as possible
- Monitoring subscriber behavior
- Providing optimum services to mobile subscribers.

And the PM applications can also "be divided to two categories depending how the applications use the collected data. These categories are called performance monitoring and performance reporting" (Engineering, 2015), *i.e*, the performance reporting can be seen in Figure18. It illustrates NetAct Report Creator Wizard in action.

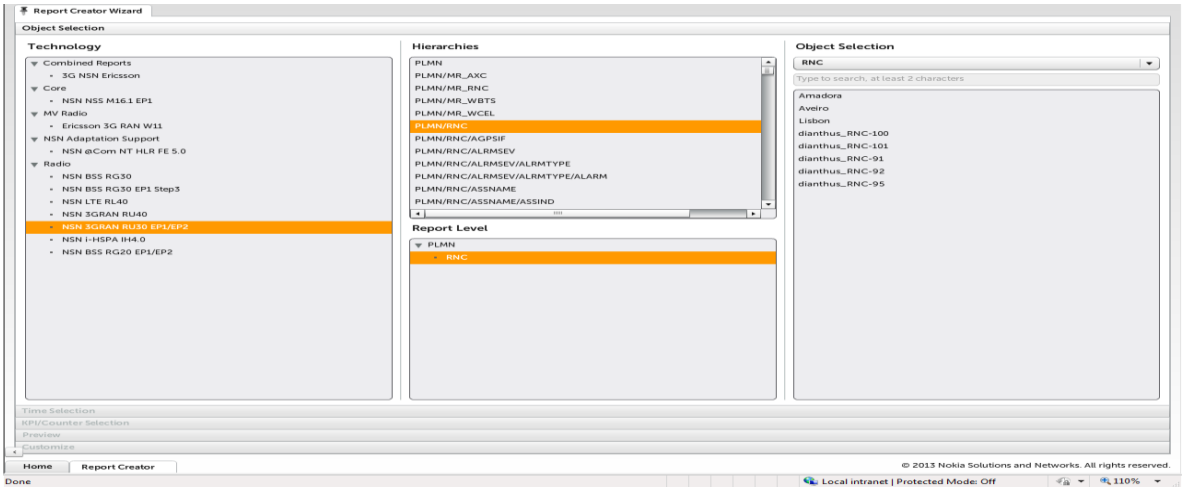

Figure18 - NetAct Performance Manager (Engineering 2015)[22]

[21] Image taken from the: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

The performance monitoring applications "are online oriented, meaning that they provide real time information on the network. The purpose of these applications is to provide additional information with short measurement output interval for problem cases where no alarm information is available. The measurement output interval determines how often and when measurement results are transferred from the network element to the NetAct database" (Engineering, 2015).

And the performance reporting applications "are offline oriented, and they provide information on what happened in the network over a certain period of time, so that the user can afterward check what caused the issue. These applications use counters, Key Performance Indicators (KPI) and produce reports. Performance reports can be used in troubleshooting, network planning or optimizing" (Engineering, 2015).

The Fault Management (*FM*) purpose "is to detect, isolate and correct malfunctions in a network as soon as they are detected by the system. *FM* consists of two applications, Monitor and Alarm Reports Dashboard" (Engineering, 2015).The Monitor application enables users to:

- Collect, process, store, and display alarm information from the network in real time
- Visualize the network topology
- Detect and analyze faults in network elements.

The "target of Alarm Reports Dashboards is to detect, collect, and store the failures in the network in a way that the users can retrospectively analyze the occurred faults and generate reports from the faults. Together with these applications the operator can troubleshoot what has caused the alarm in the network and what could be done for fixing the situation" (Engineering, 2015).

The *Security Management* (*SM*) target is "to manage and enforce security related information and policies in NetAct" (Engineering, 2015). Generally, these SM related functions can be divided into four main areas:

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[22] Image taken from the: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

- **System hardening**, meaning that the unauthorized internal and external use of the system is prevented by removing unnecessary services and usernames.
- **User security**, consisting of authentication, authorization, and user event login.
- **Network security** means the "protection of the traffic in a network where NetAct is used. Network security includes traffic access control, monitoring and protection, including encryption" (Engineering, 2015).
- **Security supervision** is performed through login and tracing.

These four areas also follow the international guidelines of confidentiality, integrity and availability.

The mobile networks operators and telecommunication provider "have developed dramatically during the last 20 years and the change is ongoing. The Figure19 below shows development in global connections by technology for six years and prediction for near future. The Figure doesn't take account to 5G or machine-to-machine (M2M) communications but shows the trend where older technologies are losing markets for newer and faster ones are gaining more market share, for example the 2G connections in 2020 is predicted to decrease to 3.2 billion" (Engineering, 2015). High number of connections is explained by multiple subscriber identity module (SIM) ownership.

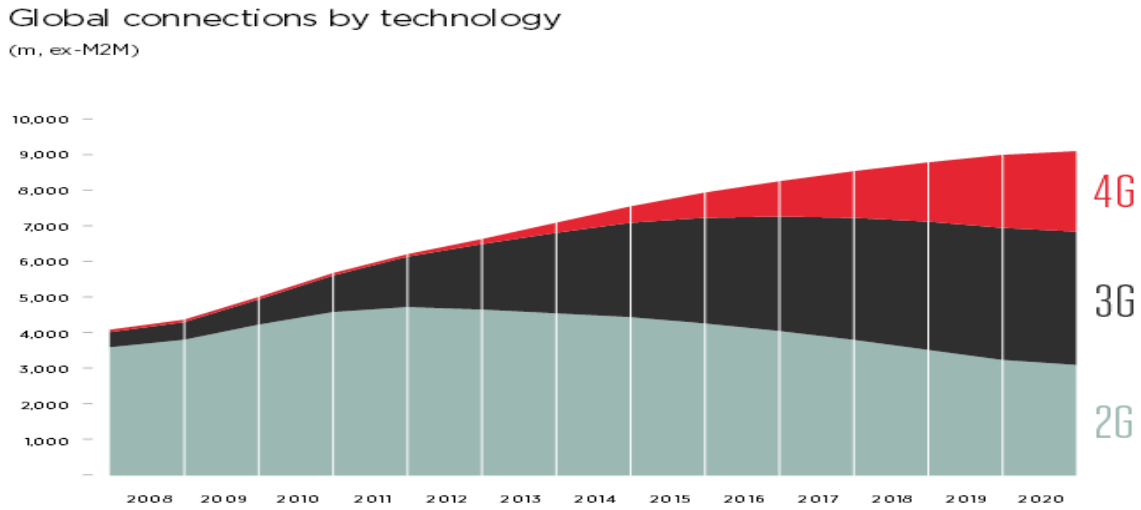


Figure 19 - Global connections by technology (Engineering 2015)[23]

[23] Image taken from the: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

A mobile operator network consists of different elements for providing telecommunication service to its customers, *i.e.*, of telecommunication operators are often multinational companies, like Vodaphone or TeliaSonera. The “operator network itself is formed from several different network elements and core networks. It is useful for a NetAct tester or anyone who works with radio networks to understand the differences and functionalities between different radio access technologies. This way he or she can form the big picture about the radio networks and understand how different network elements affect each other and what the differences are between different radio access technologies” (Engineering, 2015).

The one of NetAct infrastructure, is the system load that`s “defined as the amount of resource utilization of the system. Typically, from a hardware perspective, the system load is presented as an average system load. Its definition is an average number of processes in the CPU waiting queue per unit time. System load average helps to narrow down problems in performance testing. *I.e.*, if the average load is the same at a bad situation as in the normal situation, then the performance issues must be looked somewhere else” (Engineering, 2015).

From NetAct perspective the system load is seen as events caused by users in management systems through northbound interface, network elements through southbound interface and system itself with different management applications. These causes are seen in Figure 120 which illustrates the NetAct infrastructure.

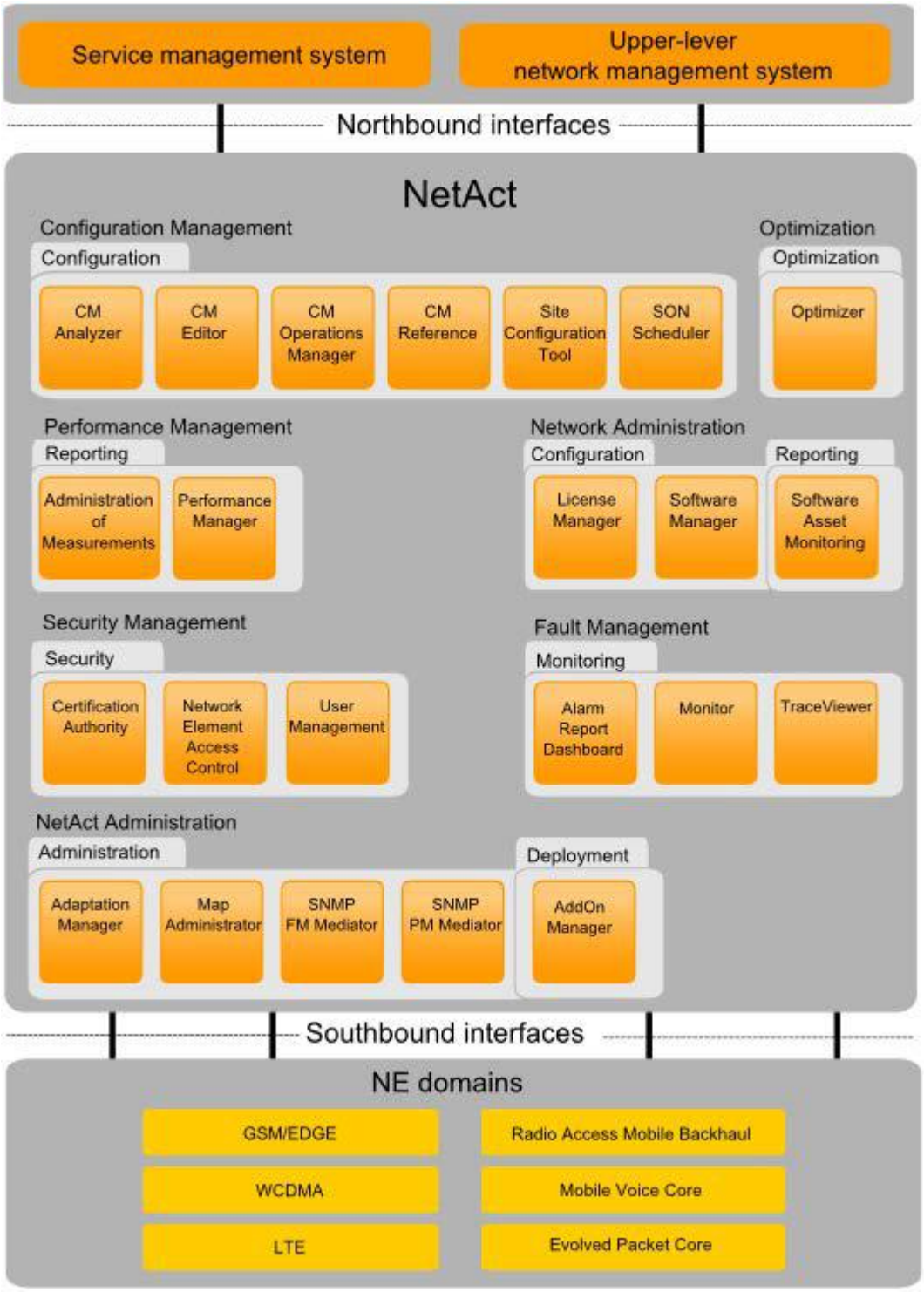


Figure 20 - NetAct infrastructure (Engineering 2015)[24]

Internal load in NetAct comes mainly from database I/O operations and user actions. Overall causes for increased system load may vary from a high number of simultaneous user events to a bottleneck situation caused by hardware failure.

[24] Image taken from the: https://dspace.cc.tut.fi/dpub/bitstream/handle/123456789/22812/Developing%20a%20dimensioning%20model%20for%20NetAct%20performance%20testing.pdf;sequence=1

The one of important thing that the Netact provide is the performance test where sometime “testing cannot prove that there are no defects in the software, and it does not improve the quality of the software but measures it. It is also not about making sure that the software works as it is supposed to work, because the person designing the test cases sees only what he or she wants to see. Therefore, a successful test run is one that causes a failure” (Engineering, 2015).

A failure in testing is an event that is externally observed and is caused by a fault, even if all faults do not lead to a failure. Testing is an important part of software development process alongside coding. Traditionally testing envolves certain phases like as:

- Test design
- Creation of test cases
- Executing the test cases
- Evaluating and reporting the results of the test runs.

Overall testing can be divided to several different categories and one of them is performance testing. “Performance testing is part of system testing and its objective is to uncover bottlenecks in performance, determine or validate the speed, scalability, and stability characteristics of the product under test via technical investigation. Therefore, in order to comprehensively determine the run time performance, performance tests are often coupled with stress testing and usually require both hardware and software instrumentation. This is because often it is necessary to measure hardware resource utilization in demanding fashion” (Engineering, 2015).

In the NetAct performance testing, the simulators play an important role because with them the testers create scenarios which simulate operator networks with certain number of network elements and network functionalities. The “simulators functionality is monitored with software called Introscope. The general target in NetAct performance testing is to ensure that the resource usage and system speed of the newer release is in balance. Therefore, one key target of NetAct performance testing is to ensure that the new system release is capable to handle the same amounts of load and users as the previous release. In practice this means that the system is tested with the same load and simulator versions as in the previous release” (Engineering, 2015).

The Keys types of performance testing can be divided into several sub-categories by test type. In order to "benefit from performance testing, it is important to understand the differences between these performance test types. By understanding different test types, testers are able to decide when to apply an appropriate test over the course of a given performance testing project; this reduces risks and minimizes costs of the project" (Engineering, 2015).

In literature, performance testing is often categorized from three to seven major categories. Usually some additional concepts are also used due to the different test environments and needs. The following list introduce the three major categories of performance testing and some of the additional concepts like as:

- **Load test** focuses on the system's" capability to handle increasing levels of anticipated realistic loads resulting from the transaction requests generated by numbers of concurrent users or processes" (Engineering, 2015).
- **Stress test** focuses on testing "the ability of a system or a component to handle peak loads at or beyond the limits of its anticipated or specified workloads, or with reduced availability of resources such as accessible computer capacity and available bandwidth" (Engineering, 2015).
- **Scalability / Capacity test** focuses "on the system's ability to meet future efficiency requirements and capability to handle defined user transactions while maintaining defined performance goals" (Engineering, 2015).

There are some additional concepts commonly used in performance and other types of testing:

- **Component test** is any performance test that targets an architectural component of the application or system.
- **Smoke test** is the initial run of a performance test to see if application can per-form its operations under a normal load.
- **Unit test** is any test that targets on verification of module of code, with focus on performance characteristics. Unit testing also includes **regression testing**.

- **Validation test** focuses on testing the product if it meets the defined criteria and works as intended.

In NetAct performance testing, the "emphasis is generally on *stability or also called soak testing* while testing also includes dimensioning, load, stress and overload tests. Stability testing can be categorized under stress testing and its target is to determine how long the system can operate under a defined workload and what kind of errors occur during the workload" (Engineering, 2015).

Practically this means that in the NetAct stability testing, the system is run with moderate loads while having some management functions and network elements. Stability tests include combined network element mixes while testing all interfaces simultaneously. The "target of stability testing is to test, the set performance requirements to identify problems that may appear only after an extended period of time and check if the system. The target of overload testing is to exceed the upper limits of the system while observing the behavior of the system and its components" (Engineering, 2015).

NetAct is tested for FM, PM and CM components. Tested "metrics for the mentioned components vary from a number of alarms or events in a specific time span. Alarm in FM can rise from several combined events or a single severe problem in the network. It produces an integer value for the occurred event. In some occasions processed metric values are used as well" (Engineering, 2015).

The HSDPA was introduced by the "3rd 3GPP to satisfy the demands for high speed data transfer in the downlink direction in UMTS networks. It can offer peak data rates of up to 10 Mbps, which is achieved essentially by the use of Adaptive Modulation and Coding (AMC), extensive multicode operation and a retransmission strategy" (Do, Do, & Chakka, 2014).

However, "efficient operation of HSDPA does require fast performance evaluation models in order to design, dimension, operate, maintain and update the system, both costs effectively and efficiently. Such a performance model should be able to accommodate simultaneously all the important features and aspects pertaining to the

operation of HSDPA, *e.g.*, burstiness and the correlation amongst data traffic, channel assignments between voice and data traffic, channel coding schemes, as well as effects of the wireless environment such as channel fading" (Do et al., 2014).

In the implementation of HSDPA, several channels where traffic the data rate in in cells are introduced in Figure15. The "transport channel carrying the Max number of HSDPA user per cell of data traffic, in HSDPA operation, The High-Speed Shared Control Channel (HS-SCCH), used as the downlink (DL) signaling channel for cells, carries key physical layer control information to support the demodulation of the data on the HS-DSCH"(Do *et al*., 2014).

CHAPTER 3 – SOFTWARE ENGINEER ARCHITECTURE

" Knowledge grows exponentially. The more we know, the greater our ability to learn, and the faster we expand our knowledge base."

(Dan Brown)
"The Lost Symbol"

This chapter presents the conceptual architecture of the inference mechanisms for visual models of knowledge representation: the definition of the architecture proposed in this research, Use Cases and Class Diagrams are also will be addressed in project engineering, how they are organized, what their processes are and what are the techniques and technologies adopted. Each of the technological solutions used is presented and explored in order to know its potentialities and applications.

To describe the conceptual architecture of this project, this chapter is organized as follows:

- ***Section 3.1*:** presents the research design where it is possible to identify the main actor of the system and describe their functions of each user.
- ***Section 3.2:*** describes the use-case model and capturing the functionalities that the system behavior of the architecture provided.
- ***Section 3.3:*** describes the structural conceptual model to capture the information that the system represented to provide the functionalities.
- ***Section 3.4:*** describes the relational model of database of automatized system that help to persist and ensure that the information from application is save I data base correctly.
- ***Section 3.5:*** Presents some considerations about the architecture, techniques, concepts and technologies adopted of system, the tools chosen language of programming, data base and how the system functioning, and some consideration presented in this chapter.

3.1. Research Design

To understand the system, one must understand what types of users the system will have. In the planning context, we use the word "Actor" to refer users or systems that interact with the functionality of the interface. Three types of actors were planned, and their representations are described in the table 7:

Table 7 - The System User

Actor	Description
User	Represents the user that has a system registry and is authenticated to it.
Administrator	Represents the user responsible for the control and maintenance of the system.

Once the registration is done, the user can perform the authentication with the registered data. In terms of planning of behavioral state and becomes understood as user.

The main functionality and the basic flow of the system related to the functionalities and service that the main system provides with total accessibility. And to access the functionality of the system, the user will authenticate with the login and password and click in *sing in* to access an external client application to get the client server or ssh remotely using the client login and password to authenticate in client server or ssh and will open a page that shows the services that the system provides.

If user/engineer wants to search the site, create the new site, create and run adjacency, create the view, create and delete the rout, configurate and access the sites to verify the configuration, upload the license to performance the site, make test calls in each cell to charge the fee, alarm test, the interface configuration, etc. The system allows the user/engineer to planning and integrate the site and analyse the KPIs in different technologies and media transmission to assess and measure the performance to telecommunication providers and operators.

The *User Administrator* has the role to control the system. It can monitor the system, who or how users are interacting with the system which time, who have register in system and enforcing rules for proper use of the system, the maintenance in system, data base.

3.2. Use Case Design

The use-case model aims at capturing and describing the functionalities that a system must provide for the actors that interact with it. The actors identified in the context of this project were described in the previous section previous chapter. The following are use case diagrams and associated descriptions for each case in diagrams.

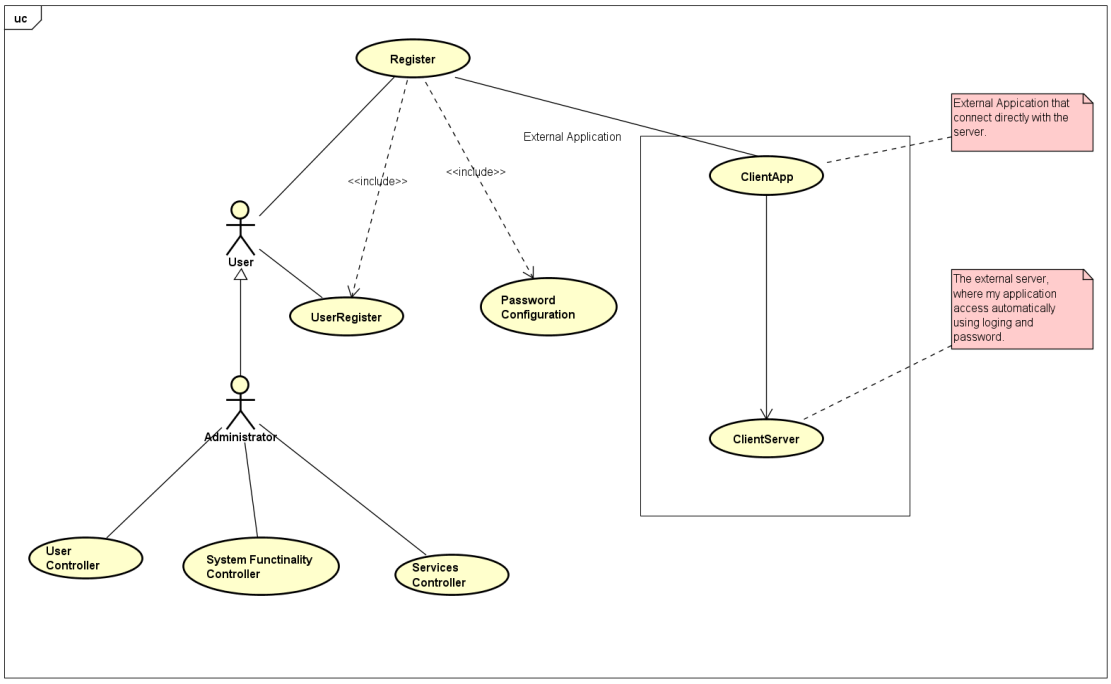


Figure 21 - Automated System Use Case

Below are descriptions of each of the identified use cases. The cases of low complexity registered use involving *inclusion*, *alteration*, *consultation* and *exclusion* are described in the table 8. The possible Include, Change, Query, and Delete actions are represented by their initials

Table 8 - Low Complexity Use Case

Low Complexity Use Case			
Use-Case	**Possible Actions**	**Comments**	**Classes**
Register	I, A, C, E	[I] You should register in system to be the system user. [I] Inform: first name, last name, email, date of birth, login, password and confirm password [C] Password and confirm password field should not be displayed	Users, Administrators
User Register	I, A, C, E	[I] User register can acess the the system. [I] Inform: name, password. [C] Password field should not be displayed	Users, Administrators

		[C] The functionality and service of the System should be displayed by user when accessing the System. [A] Administrator can control the user on the system. [E] Only administrator can delete.	
Password configuration	C	[C] The system must allow the user to change the password.	Users, Administrators
ClientApplication	C	[C] The client application must allow the user register in system to access the functionality	ClientApplication System
ClientServer	C	[C] The client server must display the username and password filed to user typing the server credential remotely	ClientServer Application System Remotely
ClientServer	C	[C] The client	ClientServer Application System

		server must allow the user authenticated to access the functionalities of system remotely.	Remotely
ClientServer	C	[C] The client server must allow the user/ engineer authenticated to access the functionalities of system remotely to configured.	ClientServer Application System Remotely
Services Control	I, A, C, E	Administrator has permission to all features related to the services	Services
System Functionality Control	I, A, C, E	Administrator has permission to all system features	Functionality
User Control	I, A, C, E	Administrator is allowed all features related to the Users class	User

This use case is responsible for adding new users to the system, as well as changing, querying, and deleting user accounts in the context of project engineering.

Table 9 - Use Case Register User-Normal Event Flow

Normal Event Flow	
Normal Event Flow Name	**Description**
	1. Inform (Required): 1.1. The First Name 1.2 The Last Name 1.3 The Email 1.4 The Date of Birth

Include New User	1.5 The username 1.6 The user password 1.7 Repeat the same user password
Reset Password	1. Inform (Required): 1.1. The username 1.2 The new user password 1.3 Repeat the same user password

3.3. Structural Model

The structural conceptual model aims to capture and describe the information (*classes*, *associations* and *attributes*) that the system must represent to provide the functionalities described in the previous section. Where the following description shows each diagrams functionality

- ***User Type*** – Present the type of user access in system, that can be administrator user and normal user.
- ***User Administrator*** – Represents the user responsible role to control the system. It can monitor the system, who or how users are interacting with the system which time, who have register in system and enforcing rules for proper use of the system, the maintenance in system, data base.
- ***User System*** - Represents the user that has a system registry and is authenticated to it.
- ***App Register*** – Represent the user register control, the user administrator is responsible of to control the user of system.
- ***App Client*** – Represent the un external application where it can communicate with the Desktop external system remotely.
- ***User App Register*** – Represent the user register that allow the user to register in the system.
- ***Password Configuration*** – Represent the system control of changing and upgrade password of system user.
- ***Server*** - Represent the un external client server to get access the tool remotely.

The class diagrams show each of the subsystems identified in the context of this project are presented in the Figure 22.

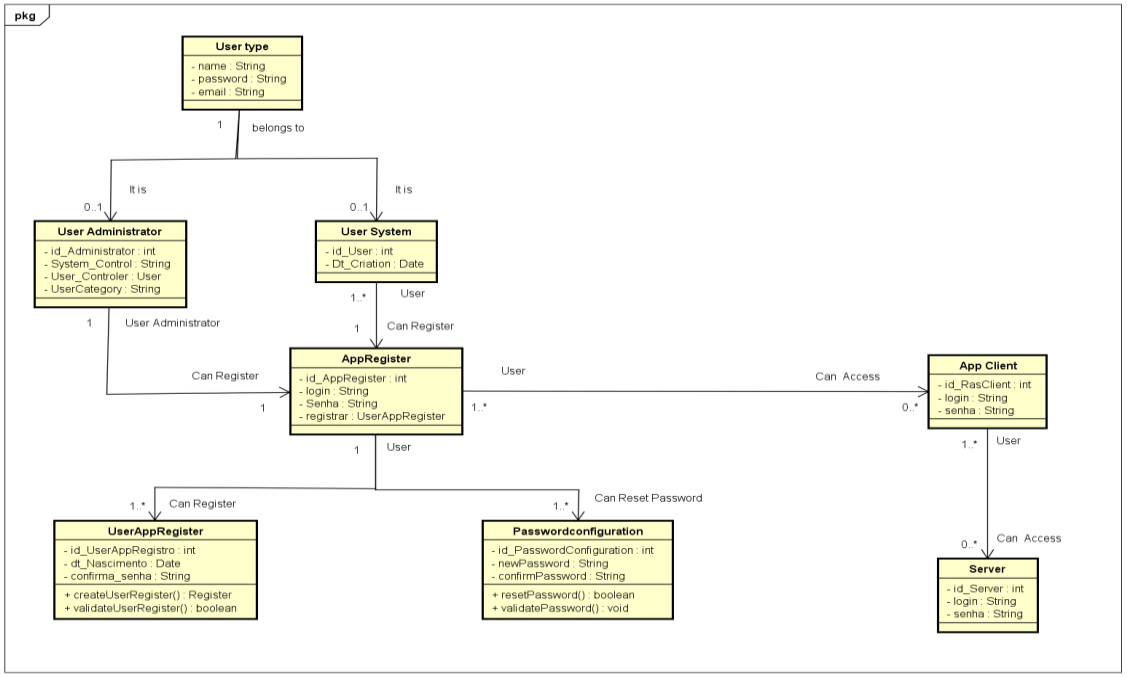


Figure 22 - Project Class Diagram

3.4. Data Base Relational Model

The relational model “has been the most widely used model in database area. It was proposed in 1970 and revolutionized the database field. Besides the new trends in software, like the object-oriented approach, the relational model is the dominant model in database market” (Ant & Nunes, 2010).

The better way to ensure a good communication between application system with data base is to build the diagram of *Entity-Relationship Model* (*MER*), and modeling to transform data from logical model to physical model this relational model that will in fact be deployed in MySQL DBMS, since it has all the attributes because they will be useful whenever software development is necessary. This help to persist and ensure that the information is save in data base correctly.

The Figure 23 shows the Automatized System logical data base project.

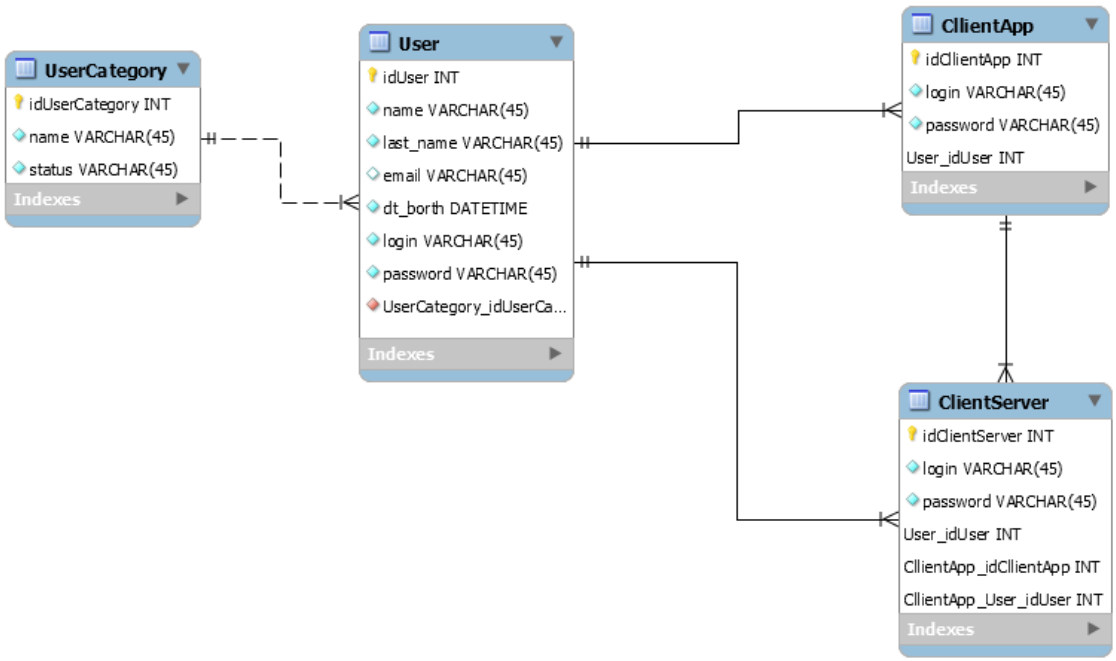


Figure 23 - The Automatized System logical model data base project

3.5. Concepts and Technologies Adopted

The automatized system is an application oriented to several functionalities, among them the user registration interface, the client application interface and the Client Server interface. In this work the aim is to build the application that allow the user make register, create an account filling out form to save in data base to ensure system control of users to know who is using the system. After register the user can *sign in* system using the user and password to access the system automatically. And to change the password the system, the application opens other windows to reset and change your password, and only the user administrator has a permission to delete the user.

The aim of automatized system is to create the application that communicate with an external existent application automatically using the client login and password to access the Client Application and server remotely to analyse different functionality in each technology like *GSM*, *UMTS* and *LTE*. And, to assess the distinct functionality to integrate the distinct type of transmission media in sites to help the telecommunication network provider and operator to perform the modernization like as:

- Create a new site on a controller (*RNC*/*BSC*);
- Increase the carrier;
- Change type of transmission media (*ATM*, *IUB*, *DUAL IUB*, *FULL IP*);
- Perform call tests in (MSS) to get the voice data and video traffic in each cells and carrier to help operator to charge the fee and to add performance in (*RNC*/*BSC*) controller;
- Perform call alarms (Internal and External) generate by system;
- *BTS*/*LTE*/*SRAN* configuration;
- Upload licenses and increase power on sites;
- Parameter setting correction;
- Hardware Modernization in Radio module and system;
- Configuration in exchange of equipment from a different sell;
- Create and configure the virtual channels interface;
- Create new route in exchange in type of transmission media;
- Delete the all route in exchange in type of transmission media;

- Request and create the adjacency to integrate a new site;
- Create coco in new site in transmission media (*ATM*);
- Delete coco in exchange of transmission media (*ATM* to *FULL IP*)
- Create core in RNC to associate in integration to a new site;

These functionalities increase the performance and help to access the *KPI* of each technology to telecommunication provider and operators.

The *Automatized system* has new tools in its proposal. The following technologies will be described, preceded by theoretical bases. In "the *Model-View-Controller* (*MVC*) paradigm, user input, external world modeling, and visual feedback to the user are explicitly separated and manipulated by three layers, each specialized in a given task" (Burbeck, 1992). like as:

- *The View manages* the graphical or textual output of your application.
- *The Controller* is responsible for manipulating user input, commanding the View and / or Model to change as needed.
- Finally, "*Model manages* application domain behavior and data, responds to requests for reading, writing, and modifying data. The formal separation of these three tasks is an important concept and provides a flexible and powerful tool" (Burbeck, 1992).

The *MVC* standard *framework*[25] for web applications. Basically, this tool uses the *Model layer* for interactions with the database, the *View* to display the data output, and the *Controller layer* to interpret input commands and manage the flow of a system. The tools chosen and that support these frameworks are common in application or web development and are available on most hosting services.

We decide to choose platform of development like as:

- *eclipse IDE* in the context of computing, "is an integrated development environment (*IDE*) for developing applications using the Java programming

[25]*Framework* is a set of classes that collaborate to perform a responsibility for a domain of an application subsystem

language and other programming languages such as *C/C++*, *Python*, *PERL*, Ruby, and Eclipse PDT for *PHP*, among others" (Java & Concepts, 2015).

- The *XAMPP* allows you to "develop PHP and Perl-based server-side scripting applications and connect to *MySQL* database without the need for a remote web server, offering you the opportunity to work faster, develop stuff more securely, and work on your apps without an internet connection" ("Using *XAMPP* for Local WordPress Theme Development," 2015).
- The *MySQL database* is the "repository probably the most widely used database engine in the world, supporting a wide range of services. All that is open source platforms such as WordPress, Joomla or Drupal, use *MySQL* as a database" (Manual, 2013).
- The *Java programming language* is a "high-level programming language originally developed by Sun Microsystems and released in 1995. Java runs on a variety of platforms, such as Windows, Mac OS, and the various versions of *UNIX*. And is a language-oriented object known worldwide well common for development of applications such as for web system, embedded. android" (Started, n.d.).
- *Scene Builder framework* "is enables you to quickly design JavaFX application user interfaces by dragging an *Unser Interface* (UI) component from a library of UI components and dropping it into a content view area. The FXML code for the UI layout that you create in the tool is automatically generated in the background. It`s also can be used as a standalone design tool, but it can also be used in conjunction with Java IDEs so that you can use the *Integrated Development Environment* (IDE) to write, build, and run the controller source code that you use with your application's user interface. Although Scene Builder is more tightly integrated with Java IDE, the integration enables you to open an FXML document using Scene Builder, run the Scene Builder samples, and generate a template for the controller source file" (Castillo, 2014).

CHAPTER 4 – ARCHITECTURE AND TECHNOLOGY

" The project is the sketch of the future."

(Jules Renard)

With the requirements raised and the technical data ready in chapter 3, in this chapter presents the conceptual of the system creation phase began. This section describes the system created and shows in a practical way all the features of it, making it clear how to use the automatized system, what are the techniques and technologies adopted and all also will be addressed in project engineering. Each of the technological solutions used is presented and explored in order to know its potentialities and applications proposed in this research and the results obtained is presented in Chapter 5.

To describe the conceptual architecture of this project, this chapter is organized as follows sections:

- ***Section 4.1:*** presents the automatized system overview where it is possible to identify the main functionality and components of the system and describe the functionalities of system.
- ***Section 4.2:*** describes the automatized system home screen functionality and the system behavior in order to understand.
- ***Section 4.3:*** Presents the user register form windows that allow the new user to register in system to have access in external client application remotely after registration.
- ***Section 4.4:*** presents the architecture overview where it is possible to identify the main modules and components of the system and describe their functions and user experiences.
- ***Section 4.5:*** describes the activities and sequential behavior of the architecture in order to understand its internal functioning.
- ***Section 4.6:*** Provides some considerations as presented in this chapter.

4.1. The Overview Automatized System Functionality

The automatized system is an application oriented to several functionalities, among them the user registration interface, the client application interface and the Client Server interface. In this work the aim is to build the application that allow the user make register, create an account filling out form to save in data base to ensure system control of users to know who is using the system. After register the user can sign in system using the user and password to access the system automatically. And to change the password in the system, the application opens other windows to reset and change your password, and only the user administrator has a permission to delete the user.

The aim of automatized system is to create the application that communicate with an external existent application automatically using the client login and password to access the Client Application and server remotely to analyse different functionality in each technology like GSM, UMTS and LTE. And, to assess the different functionality to integrate the different type of transmission media in sites to help the telecommunication network provider and operator to perform the modernization like as:

- Create a new site on a controller (RNC/BSC);
- Increase the carrier;
- Change type of transmission media (ATM, IUB, DUAL IUB, FULL IP);
- Perform call tests in (MSS) to get the voice data and video traffic in each cells and carrier to help operator to charge the fee and to add performance in (RNC/BSC) controller;
- Perform call alarms (Internal and External) generate by system;
- BTS/LTE/SRAN configuration;
- Upload licenses and increase power on sites;
- Parameter setting correction;
- Hardware Modernization in Radio module and system;
- Configuration in exchange of equipment from a different sell;
- Create and configure the virtual channels interface;
- Create new route in exchange in type of transmission media;
- Delete the all route in exchange in type of transmission media;
- Request and create the adjacency to integrate a new site;

- Create coco in new site in transmission media (ATM);
- Delete coco in exchange of transmission media (ATM to FULL IP);
- Create core in RNC to associate in integration to a new site.

In this thesis we choose the Netact KPI analyse to assess the telecommunication system functionality to increase the performance and help telecommunication provider and operators to analyze the KPI of each technology.

4.2. The Automatized System Interface Functionality

In this section we start to follow the automatized system functionality screen, to integrating the principles of design, process and standards is the key to designing interfaces effectively. The integration of these items results in an automatized system interface of good quality and objective. However, quality is always tied to the context, *i.e*, who the user is, what he wants to do, and what his motivations are.

And it is because of "the context factor that the concept of "*one-size-fits-all*[26]*"*, does not necessarily mean that the result is better, however much that design facilitates the creation of interfaces. To create good design solutions, the effort to truly understand the people who interact with your product is essential. To understand the people who interact with your product, only then does it become useful to have a range of principles and standards to apply in a specific situation" (Cooper, et al., 2007).

First, when you come across the created interface, the user will see the main home screen. This is the screen that the user must use whenever he needs to access the system functionality, to access the system functionalities, the user must register in system click in *sign up* button, the system will open other windows form to register the new user fill the form with the his/her information and save it in system data base. When the user is already register in system (system user), he/she can authenticate in the system using the *login* and *password* to access the client application using button *sign in*. If the user forgot password in home screen, the user can choose the button *forgot password* to change the password in system. The Figure 24 shows the home screen automatized system.

[26] *one-size-fits-all:* An expression that means that one size fits all. One solution for everyone.

Figure 24 - Automatized Screen

The Figure 24 shows the automatized system home screen where the main users interested in the automatized system (interacting with the system) like as:

- The telecommunication provider
- The telecommunication operators
- The telecommunication employer

The automatized system as two text field *login* and *password* to authenticate in system and three buttons *sign in*, *sign up* and *forgot password*. Where the user can choose these three options in system.

When the user system forgot password, in home screen the button forgot password can help user to change password, click in button the system will open other windows form to fill the username, the new password and confirm the new password and save the last information in data base system. The Figure 30 shows the forgot password windows form.

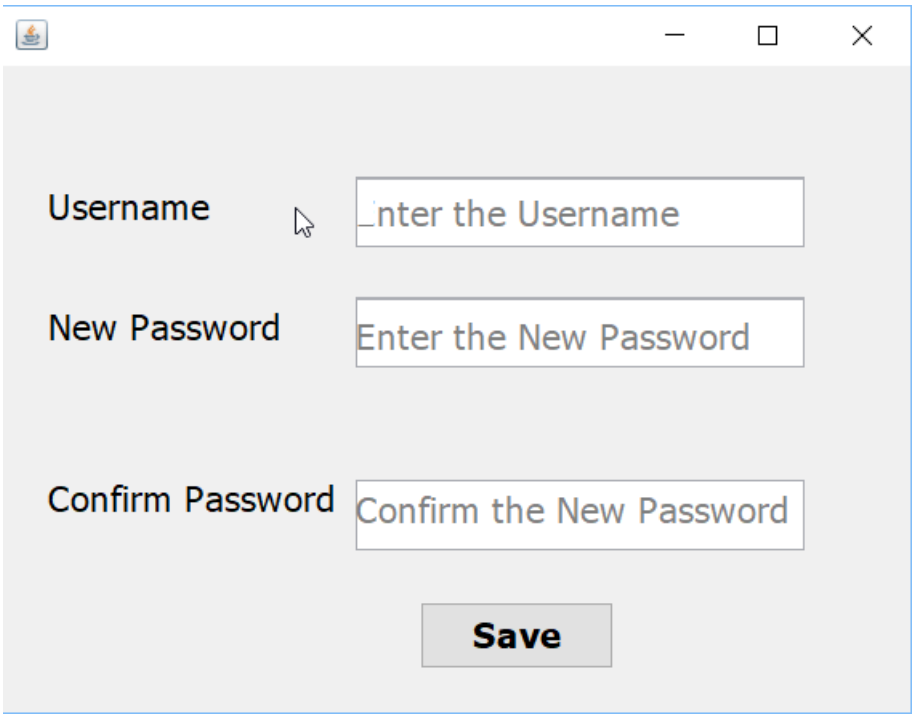


Figure 25 - Forgot Password

The Figure 25 forgot password show u how the user can change the password in system using the user and the new password in text field. To save in data base system.

Before using the system tools, needed to make register in the automatized system to have access in the external client application functionalities, clicking in *Sign-up in-home* screen where the system will open other windows form to fill the information to save in system data base or the user can cancel the registration in system. And the register screen is intuitive and simple to understand, with placeholder[27] message in all the field. The Figure 26 shows the User Register windows form.

[27] **Placeholder**: In computer programming, is a *character*, *word*, or *String* of characters that may be used to take up space until such a time that the space is needed. For example, a programmer may know that she needs a certain number of values or *variables* but doesn't yet know what to input.

Figure 26- The new user Register form

4.3. The External Client Application

The external client application is an application developed by external client where my application calls it remotely to access an external telecommunication network provider and telecommunication operator server. In other word, the external client application is a bridge to access the client server remotely. To access the external application client, the user must authenticate in automatized system using login and password, after it the external client will open getting the login and password to access the different external desktop server and shell command prompt where it allow th user or engineer to configure the telecommunication controller system remotely. The Figure 27 shows the external client application.

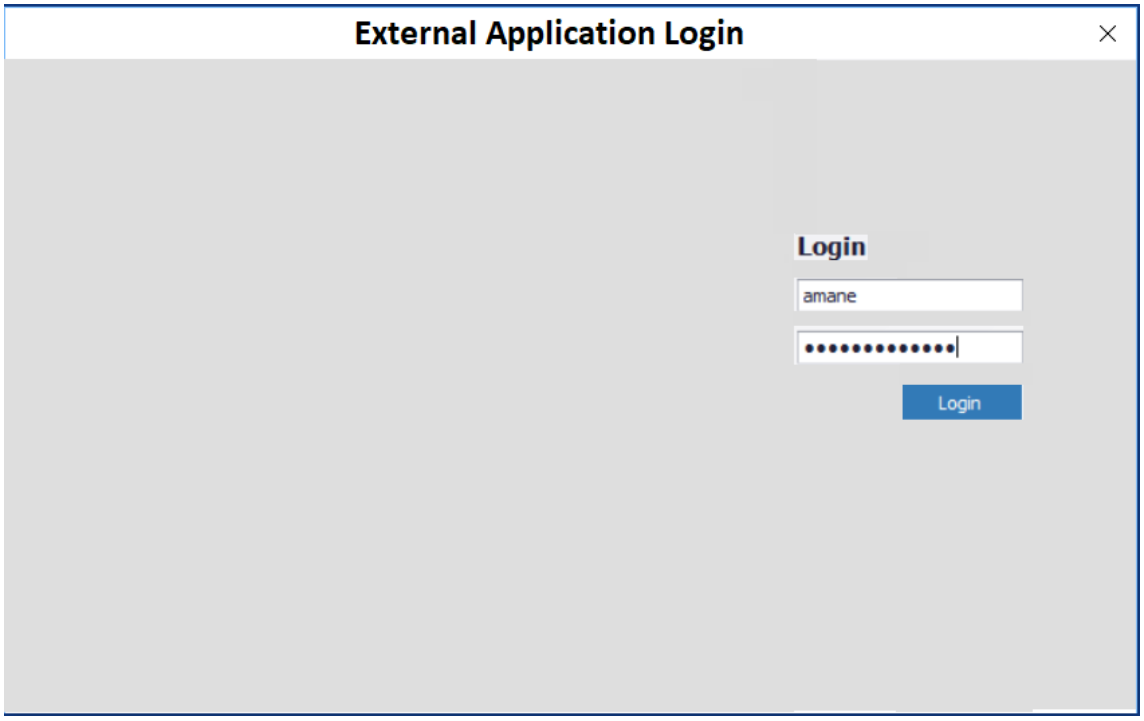


Figure 27- Client Application System source from anonymous

After authenticating in external client application, the Figure 28 shows the different desktops server and shells command prompt, where it allow to access the servers and shell command prompt remotely. To avoid exposing the confidentiality of the client name we chose to choose the different desktop server name and shell command prompt, like the anonymized.

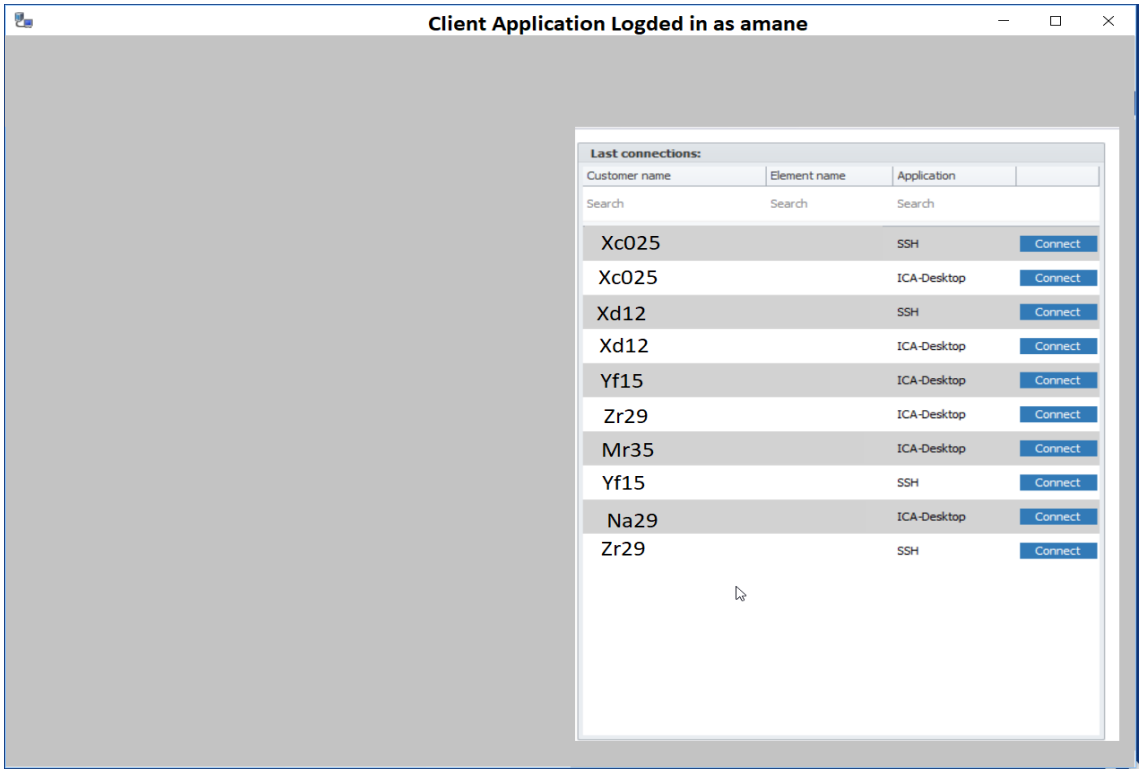


Figure 28- The Client Application Server Connection Remotely source from anonymous

The Figure 29 shows the client application desktop server connection remotely where the user or engineer can get in to the server to apply the integration configuration and analyze the KPI of sites in different technologies.

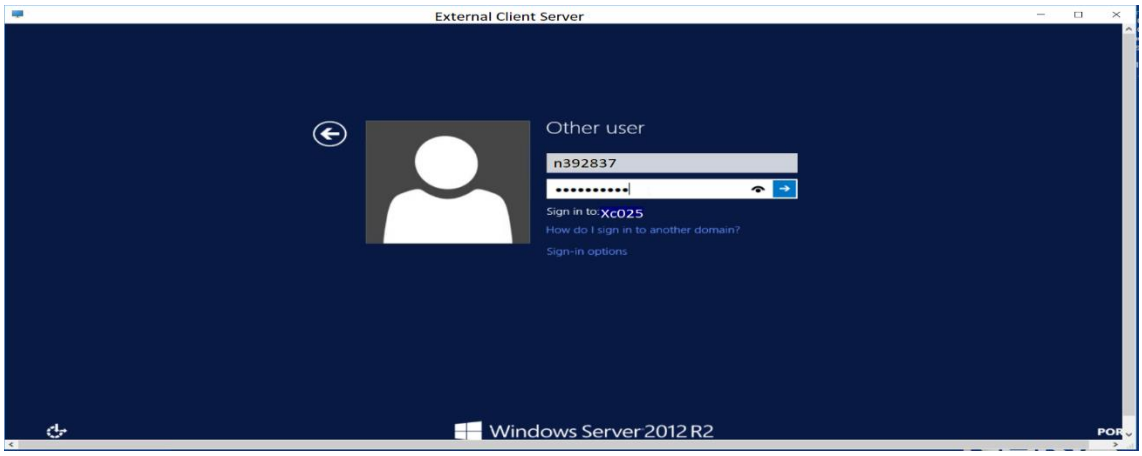


Figure 29 - The Client Application Server source from anonymous

CHAPTER 5 – RESULTS AND KPI ANALISYS

" [...] all evaluation is a product of what is evaluated by the cognitive sphere of those who evaluate."

(Arthur Schopenhauer)
"Aphorism about the Wisdom of Life"

All proposals for new computational architectures require tests that validate their applications. This chapter aims to present the all stage of mobile telecommunication network functionalities provided by telecommunication network provider and network operator presented in Chapter 4 and perform a test of concepts to analyze the results obtained and presented the initial stage as a base in building a site in a BSC or RNC, it`s the planning and then move on to the integration stage of a site to radiate with their respective cells and carriers.

To get a better understanding in this chapter, we presented the sections below like as:

- ***Section 5.1:*** presents the planning to building the site, where the telecommunication network provider engineer creates and generate the *XML* file to each new site in different technologies (*GSM*, *UMTS* and *LTE*) and adapted them to the transmission media.
- ***Section 5.2:*** Presents the site *network integration* (*NI*), where the *NI* engineer make support together with technician in field to configurate and update the sites.
- ***Section 5.3:*** Present *Single Radio Access Network* (*Single RAN*) have been the potential of the technology to simplify the ever-growing intricacy of the macro radio access layer that it is being developed rapidly and will bring many new benefits for mobile broadband operators.
- ***Section 5.4:*** Present the technology performance to increase the performance and obtain the better result in technologies, is to maintenance and update the equipment.

- ***Section 5.5:*** Present the technology KPIs analysis.to verify in what the network operators can improve or increase to improve the KPIs.
- ***Section 5.6:*** Present the technologies result, were they are radiate in each base station that makes the network operator ensure that each site is radiate normally, and also, they can monitor the site remotely to control the status on air using the application appropriate, and trough final considerations.

5.1. Site Planning

The one of better solution to improve the telecommunication network provider and network operator to building the new site, it`s *Network Planning* and *Optimization* (*NPO*) where the NPO team planning, creating and generate the excel file called by nominal plane and *XML* file also. The engineer must know the *BSC* and *RNC* antenna position to describe the information in excel filling in the new site type of activities, *BCF*/*WBTS*/*eNodeB* name, cells name, type of equipment, latitude and longitude antenna height. The following elements in excel file is:

- ***Longitude and Latitude:*** means descriptions of the location, or geographic coordinates, of a particular place on Earth using coordinate of value to detect the region geographic.
- ***LAC:*** means the Location Area Code (LAC), the technology Cell, satellite communications.
- ***RZ:*** means in ad hoc network routing protocol development has demonstrated how global route discovery can be performed more efficiently by leveraging the known topology of each node's local surrounding area (routing zone).

The Figure 30 shows the nominal plane

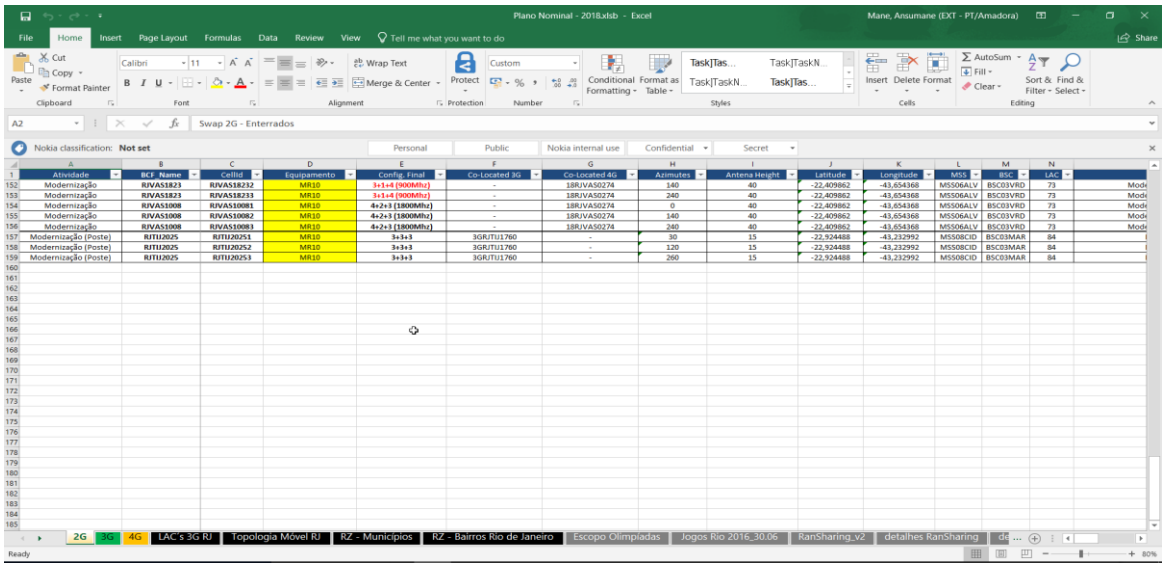


Figure 30 - The Nominal Plane source from anonymous

5.1.1. The 2G Plane

The NPO team planning to create the 2G new site in excel file filling in the all information that they planning build take in consideration the antenna position in BTS. In this excel file it has many information where this information supports the telecommunication engineer to create and configurate the new site using each information creating route and core in MSS to allow the new site to radiate normally according to the plan created by NPO team, this can procedure can increase the performance. To understand better this information, the Figure 31 shows the nominal 2G plane.

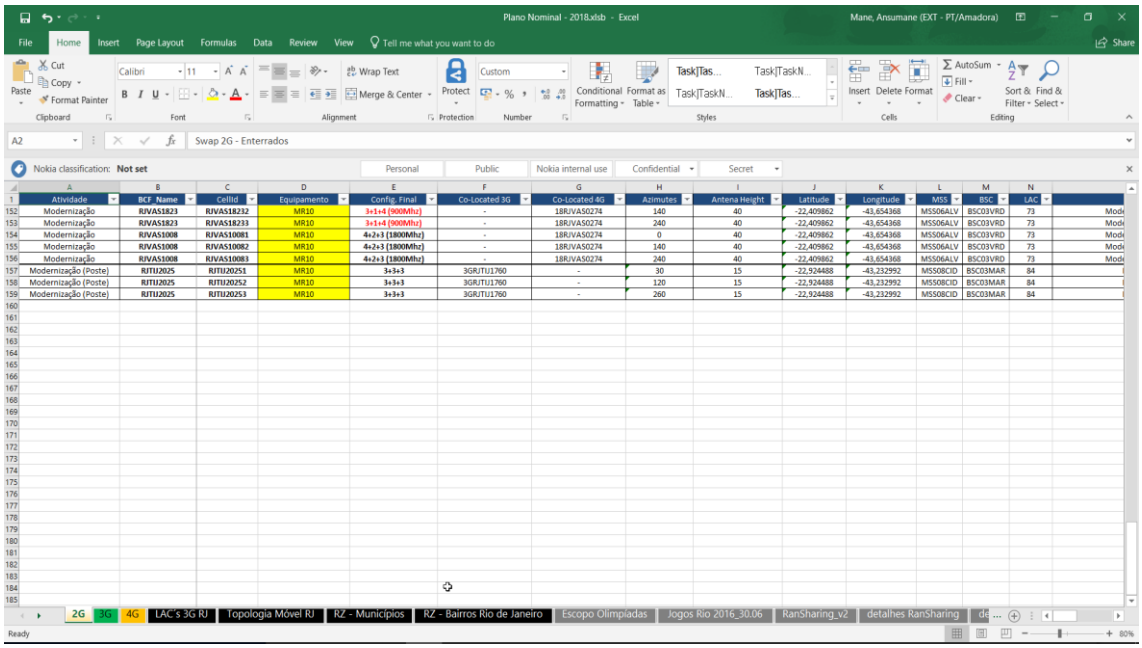


Figure 31 - The 2G Nominal Plane source from anonymous

The 2G Nominal plane include many information created by NPO team where the engineer must the following step by step with this information to configure the new site. To understand the 2G nominal plane we will summarize the information in excel file like as:

- ***Activity:*** means the type of activities the new site will have, *e.g.*, *Modernization*, *Swap 2G*, *New 2G*, etc.
- ***BCF_Name:*** means the *base control function* (*BCF*) site name the team choose to be in BSC.
- ***Cell_Id:*** means the Id of cells in certain site or in other word the number of cells name created in new site, *e.g.*, the new site can have 1, 3 or 6 cell id names of site. In each cell's id many traffic data (voice, video and data) can radiate there when the new site is on air.
- ***Equipment:*** means the type of equipment the site will radiate, *e.g.*, Multiradio, MR10, Flexi Ege, etc.
- ***MSS:*** means the *mobile switching station* (*MSS*), abbreviated as MSC Server or *MSS*, is a 2G core network Categories: Telecommunications equipment, infrastructure and Mobile telecommunications *GSM* standard.

- ***BSC:*** The *Base Station Controller* (***BSC***) is in control of and supervises several *Base Transceiver Stations (BTS*). The *BSC* is responsible for the allocation of radio where the new site is radiate.
- ***ETh***: means the transmission / connection / controller port of physical interfaces of the antenna base station (BTS/BSC), in other words intermediate of data, voice and video traffic.

This name is used in the new site configuration to put the site on air that allow the engineer to following the file as a guide to build the site.

5.1.2 The 3G Plane

In this section the 3G has the same aim with 2G, where the NPO team planning to create the 3G new site in excel file filling in the all information that they planning build take in consideration the antenna position in RNC. In this excel file it has many information this information supports the telecommunication engineer to create and configurate the new site using each information creating route and core in RNC to allow the new site to radiate normally according to the plan created by NPO team, this procedure can increase the performance. To understand better this information the Figure 32 shows the nominal 3G plane.

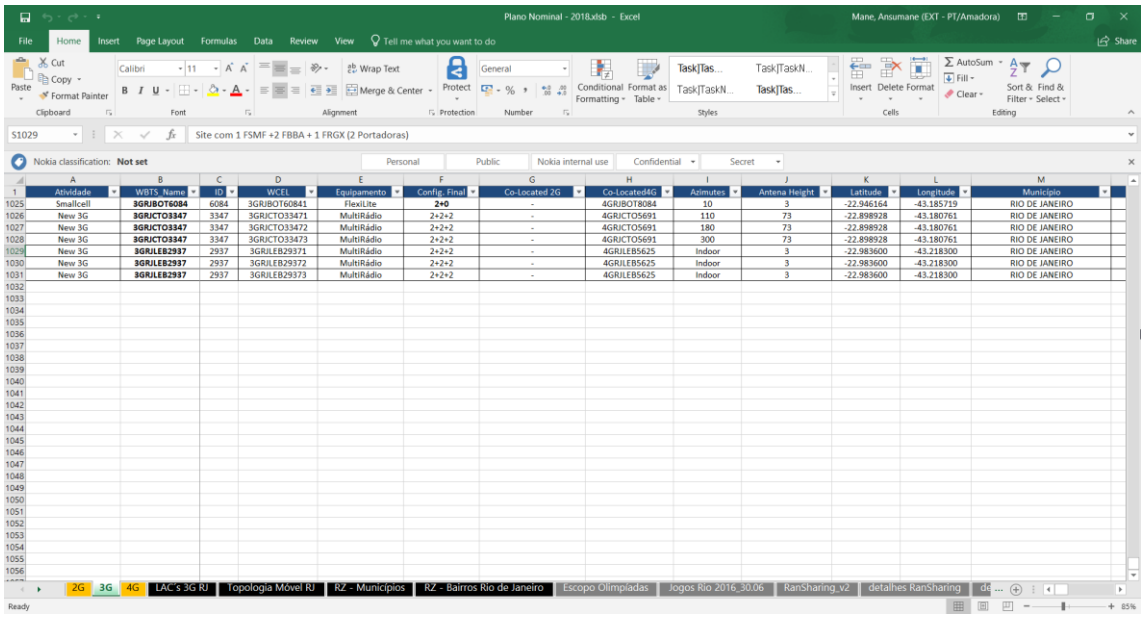


Figure 32 - The 3G Nominal Plane source from anonymous

The 3G Nominal plane include many information created by NPO team where the engineer must the following step by step with this information to configure the new site. To understand the 3G nominal plane we will summarize the information in excel file like as:

- ***Activity:*** means the type of activities the new site will have, *e.g.*, *Small cell*, *Six sector*, *New 3G*, etc.
- ***WBTS_Name:*** means the *Wide-Band Transmission System* (*WBTS*) site name the team choose to be in RNC.

- ***WCell:*** means the number of cells name created in new site, *e.g.*, the new site can have 1, 3 or 6 cell id names of site. In each cell's id many traffic data (voice, video and data) can radiate there when the new site is on air.
- ***Equipment:*** means the type of equipment the site will radiate, *e.g.*, Multiradio, MR10, Flexi Ege, *etc*.
- ***MSS:*** means the *mobile switching station* (*MSS*), abbreviated as MSC Server or *MSS*, is a 3G core network Categories: *Telecommunications* equipment, infrastructure and Mobile *telecommunications GSM* standard.
- ***RNC:*** The *Radio Network Controller* (*RNC*) handles critical functions of an UTRAN network, including: Mobility management, Call processing, Radio resource management, Link maintenance, Hand-over control, Traffic concentration and Support of mobile services.

This name is used in the new site configuration to put the site on air that allow the engineer to following the file as a guide to build the site.

5.1.3 The 4G Plane

The 4G plane was elaborate to increase the traffic rate in certain area mainly to improve the speed in telecommunication network, therefore the NPO team planning first to make the better way to reduce cost and to increase the capacity of traffic in cells allocate the engineer to building the antenna and including the 2G and 3G also to radiate in the same antenna. Therefore, the NPO team planning created the 4G new site in excel file filling in the all information that they planning build take in consideration the antenna position. In this excel file it has many information; this information supports the telecommunication engineer to create and configure the new site using each information creating route and core to allow the new site to radiate normally according to the plan created by NPO team. To understand better this information the Figure 33sohws the nominal 3G plane.

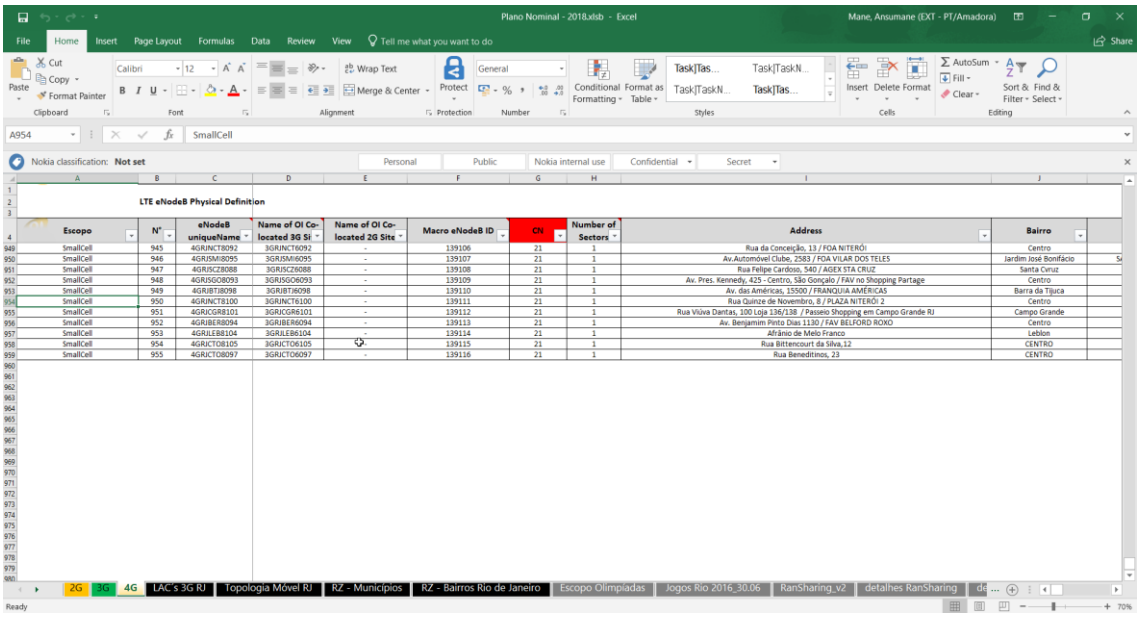


Figure 33 - The 4G Nominal Plane source from anonymous

The 4G Nominal plane include many information created by NPO team where the engineer must the following step by step with this information to configure the new site. To understand the 4G nominal plane we will summarize the information in excel file like as:

- ***Scope:*** has the type of work package (name of package) the new site will have, *e.g.*, *Small cell*, LTE 1800, etc.
- ***eNodeB_uniquename:*** means the new site name.

- ***Frequency:*** The frequency of site *e.g.*, the 700, 1800, 2100 and 2600 MHz where each cell radiate in different frequency with many traffic data (voice, video and data) on air.

All this name is used in the new site configuration to put the site on air that allow the engineer to following the file as a guide to build the site.

5.2.The Site Integration

After the make planning in BSC/RNC the integration configuration is apply to each technology. This is one of th part in Telecom, the Network Integration (NI) get in to support the site as final part. To integrate the site, it necessary to have a technical engineer in field (BSC/RNC) antennas to collaborate with the NI team support. This procedure helps the telecommunication network provider to improve the Telekom functionality and to increase the capacity of speed in telecom network.

5.2.1. The 2G Integration

After planning the 2G new site, the NI team take the excel file to create the BCF Id, BTS Id and TRX Id command, with frequency and physical interface where the data is traffic in mobile network connection according to the procedure, and this command must be run in shell command prompt remotely in BSC where the core was created to associate it to new site, and it also run the adjacency command for handover in BSCs different. The XML file crated by NPO team it also provisioned (run in tool) to associate to all IPs, VLANs to site in Figure 34, the command.

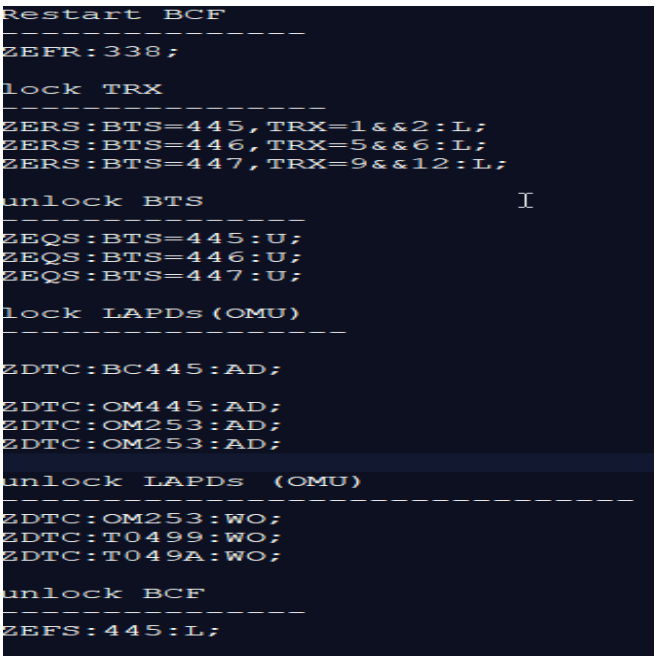


Figure 34 - The BSC Commands source from anonymous

The Figure 34 shows the command to interrogate the 2G site in *BSC*, this command allow the *NI* engineer to run command in shell command prompt remotely to

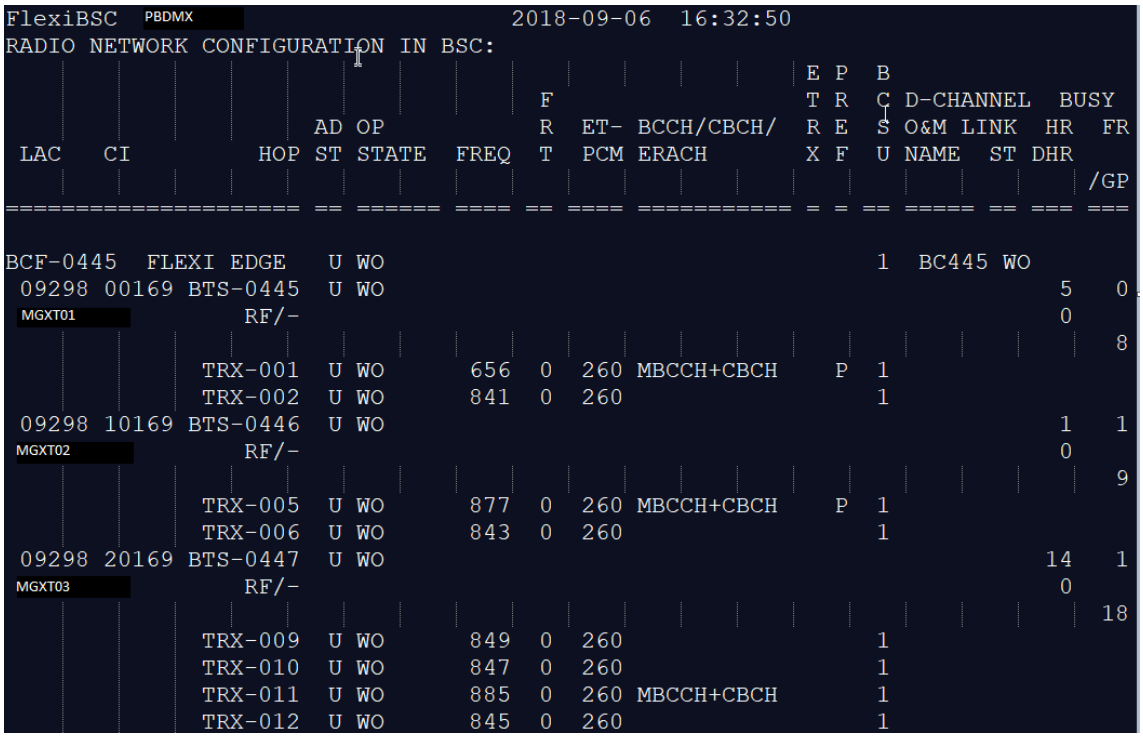
lock and unlock *BCF, BTSs, TRXs,* this procedure its done together with the technical engineer in field (*BSC*/*MSS*) and when the site is on air. The *NI* engineer must do the test call and alarm call. This test is necessary to test if the each *BTS* the calls is traffic the data and voice, this makes the telecommunication network provider and network operator can charge the fee to mobile phone users.

Reliability of telephone service "is increased by providing a test call apparatus configured to launch a test call to a preselected telephone number in response to a call from a remote location requesting that the test call be placed. The test call apparatus launches the test call as if the call were being made from the user-supplied originating area code, area code and exchange, or phone number. The test call apparatus then bridges the requesting call and the test call to facilitate analysis of the routing of the test call"(G.G. Liversidge, K.C. Cundy, J.F. Bishop, 1980).

And one the other test, is the development of an alarm device that can disseminate disaster early warnings to threatened communities over the GSM network. The "device is capable of generating audible, high volume alarms, flashlights and turning on an in-built radio in response to a warning message from an authorized entity via GSM's *short message service* (*SMS*) or *cell broadcast* (*CB*). The design of the device follows international guidelines on emergency communications, such as the ability to reach a large number of people very fast, awaken sleeping communities, and be able to acknowledge warning messages. The alarm has been designed as a last mile technology in a *larger Disaster Early Warning network* (*DEWN*). It is intended to be place in selected locations such as police stations, places of religious places and community centers"(Jayasinghe, Fahmy, Gajaweera, & Dias, 2006).

The test call is done in MSS, the alarm test and the data and voice test are done in *BSC*. The Figure 59 shows the tests in *MSS* in *Appendix A* and Figure 60 shows the tests in and *BSC* in *Appendix B.*

The Figure 37 shows the site status after integration in BSC, according to the Figure, the data traffic is ongoing in each frequency, can be Half Rate (HFR) or Full Rate (FR). And, the call is ongoing in BTS 172 in frequency channel 654, and the all TRX and BTS is in unlock (U) and working (WO) status, with the transmission media FLEXI EDGE.



```
FlexiBSC  PBDMX                    2018-09-06  16:32:50
RADIO NETWORK CONFIGURATION IN BSC:
                                                  E P  B
                                            F     T R  C D-CHANNEL   BUSY
                      AD OP                 R  ET- E F  S O&M LINK   HR  FR
 LAC    CI          HOP ST STATE   FREQ    T  PCM X X  U NAME   ST DHR
                                                                      /GP
==================== == ====== ==== == ==== = = == ===== == === ===

BCF-0445  FLEXI EDGE    U WO                              1  BC445 WO
 09298 00169 BTS-0445   U WO                                          5   0
 MGXT01           RF/-                                               0
                                                                        8
             TRX-001    U WO       656  0  260 MBCCH+CBCH    P  1
             TRX-002    U WO       841  0  260                  1
 09298 10169 BTS-0446   U WO                                          1   1
 MGXT02           RF/-                                               0
                                                                        9
             TRX-005    U WO       877  0  260 MBCCH+CBCH    P  1
             TRX-006    U WO       843  0  260                  1
 09298 20169 BTS-0447   U WO                                         14   1
 MGXT03           RF/-                                               0
                                                                       18
             TRX-009    U WO       849  0  260                  1
             TRX-010    U WO       847  0  260                  1
             TRX-011    U WO       885  0  260 MBCCH+CBCH       1
             TRX-012    U WO       845  0  260                  1
```

Figure 35 - The Site Integration Status source from anonymous

5.2.2. The 3G Integration

Differently of the 2G, the 3G after planning, the NI team following the procedure from excel file to create the route command in RNC and core command in MSS and also run this command in shell command prompt to associate each cells of a carrier in RNC. And, the NI engineer must run the XML file in tool (provisioned) to associate to all IPs, VLANs coco, VC, IPNB, and Mask. This makes the telecommunication increase the performance in 3G add the cells to radiate in the same frequency.

All this procedure is done remotely with the technical engineer in field to control the functionality, because in some case the site sometime can be down. If the technical engineer does not be in field (RNC), the integration is not done while the site is not up. And by default, the site always came locked, after the core creation in MSS and the cells must be unlocking manually, if the configuration was well configured and the command was run well, normally in few minutes the site must be on air radiating in RNC. To understand better the Figures below can explain the functionality.

```
EPO:TYPE=SA,NO=40011&&40019:;

MSCi      GDVXR34                    2018-09-13  19:54:07


SERVICE AREA DATA

SA    NAME :RJLAG40011                    NUMBER  :40011
SERVICE AREA IN MSS CONCEPT
LA    NAME :LAC0501                       LAC     :501
MOBILE COUNTRY CODE .....................(MCC)... :724
MOBILE NETWORK CODE .....................(MNC)... :31
SERVICE AREA CODE .......................(SAC)... :40011
ADMINISTRATIVE STATE ............................ :UNLOCKED

ROUTING ZONE ............................(RZ).... :265
TARIFF AREA .............................(TA).... :0
CELL DEPENDENT ROUTING ..................(CDR)... :21
CELL BAND ...............................(BAND).. : -
CELL TEST STATE .........................(TE).... :NORMAL CELL
LOCAL AREA DIALLING CODE ................(LAD)... :21
CHARGING AREA CODE ......................(CA).... : -
SUPPLEMENTARY CHARGING AREA CODES .......(SCA)... : -
NO NCAS SUPPORT..........................(NONCAS) :FALSE
POSITION DETERMINATION TIMER.............(POST).. :0 (x 10 msec)
ESRK USAGE...............................(EU).... :NO
ESRK RANGE INDEX.........................(ESRK).. :0
PARAMETER SET............................(PSET).. : -
GMLC INDEX FOR EMERGENCY SERVICES.......(ESGMLC) :0
```

Figure 36 - The Core Creation Status in MSS source from anonymous

The Figure 36 shows the core creation status in MSS executed by NI engineer to raise the site in RNC, where the site configuration provider by excel file was executed well in each line step by step. After this stage the all cells are associated with configuration. The Figure 37 shows the site lock status after core created.

WBTSId	WBTSName	WCELId	CellAdditionalInfo	CId	WCELMCC	WCELMNC	CellType	WCelState	Hig...	HSDPAenabled	HSDPAcapability	HSDSCHOpSt
364	ND3JULR25	31642	31JULR8601	31642	724	5	Not_defined	BL-USER		Enabled	HSDPA capable	Not defined
364	ND3JULR25	31643	31JULR8602	31643	724	5	Not_defined	BL-USER		Enabled	HSDPA capable	Not defined
364	ND3JULR25	31644	31JULR8603	31644	724	5	Not_defined	BL-USER		Enabled	HSDPA capable	Not defined
364	ND3JULR25	31645	31JULR8604	31645	724	5	Not_defined	BL-USER		Enabled	HSDPA capable	Not defined
364	ND3JULR25	31646	31JULR8605	31646	724	5	Not_defined	BL-USER		Enabled	HSDPA capable	Not defined
364	ND3JULR25	31647	31JULR8606	31647	724	5	Not_defined	BL-USER		Enabled	HSDPA capable	Not defined

Figure 37 - The Site Status source from anonymous

After the core creation is executed the site status remains lock until it is unlocked manually by NI engineer. In certain moment when the site is unlocked by engineer the site status switches from locked to unlocked status in figure 38 shows the unlock status on site.

WBTSId	WBTSName	WCELId	CellAdditionalInfo	CId	WCELMCC	WCELMNC	CellType	WCelState	Hig...	HSDPAenabled	HSDPAcapability	HSDSCHOpState	LAC
890	3GDPKS0890	627		627	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	628		628	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	629		629	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	8904		8904	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	8905		8905	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	8906		8906	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	38907		38907	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600

Figure 38 - The Unlock Status on Site source from anonymous

After the all this procedure finally, the site is on air and ready to receive and transceiver information to the customers in RNC where the user can use those cells depending to the coverage area of user position. And to complete one of the most important interest of telecommunication network provider and network operators, is to carry out the tests calls in the cells in order to be able to charge the rates to the customer in each call. The Figure 39 shows the test calls in cells.

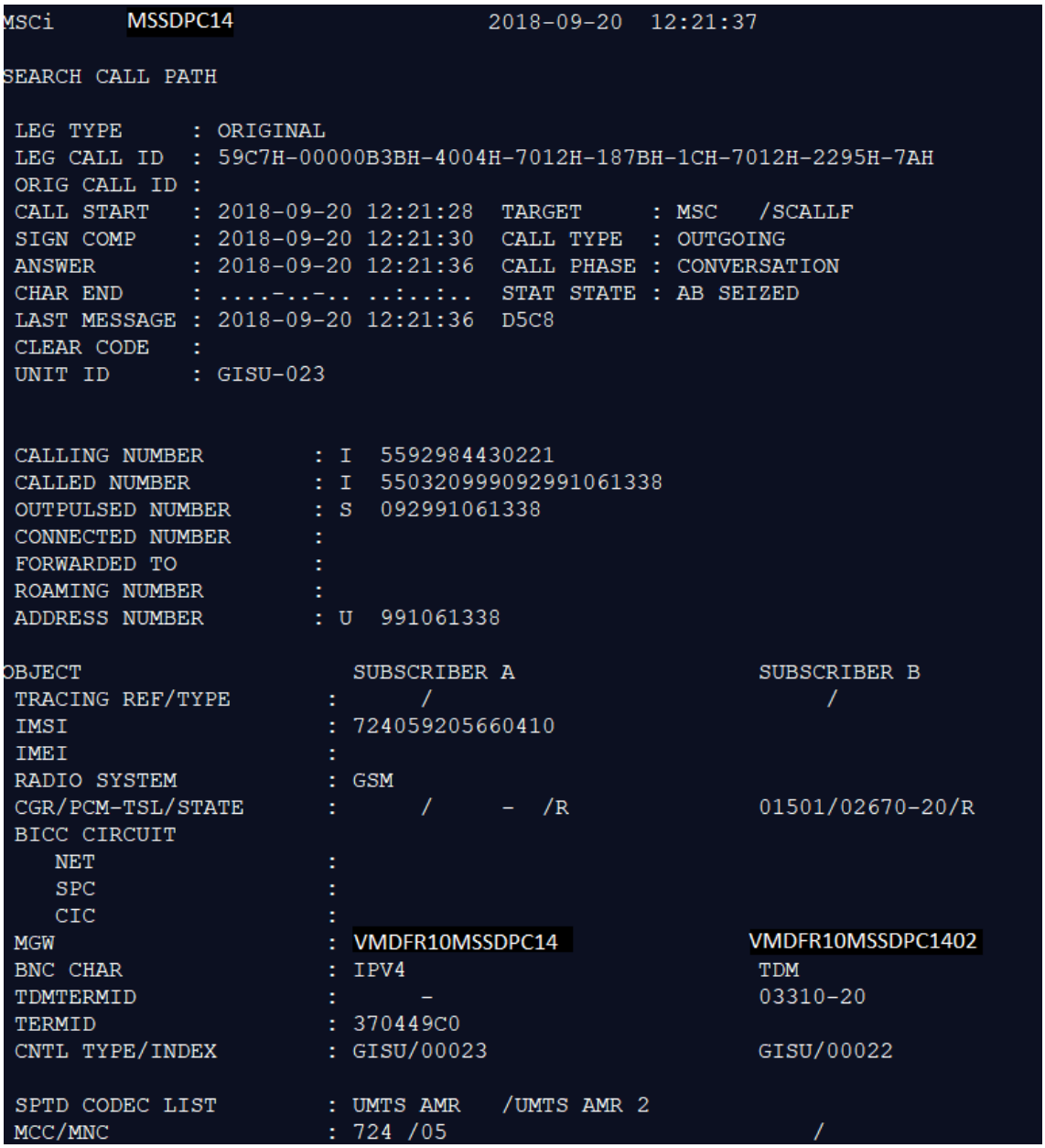


Figure 39 - Test Call source from anonymous

Like in 2G the 3G also make the test call to allow the telecommunication network provider and network operator to charge the rates to the customer, and the alarm test it also done to generate the type of alarm in site then clean all the alar on site. The Figure 40 shows the alarms generated by technical engineer in field (RNC).

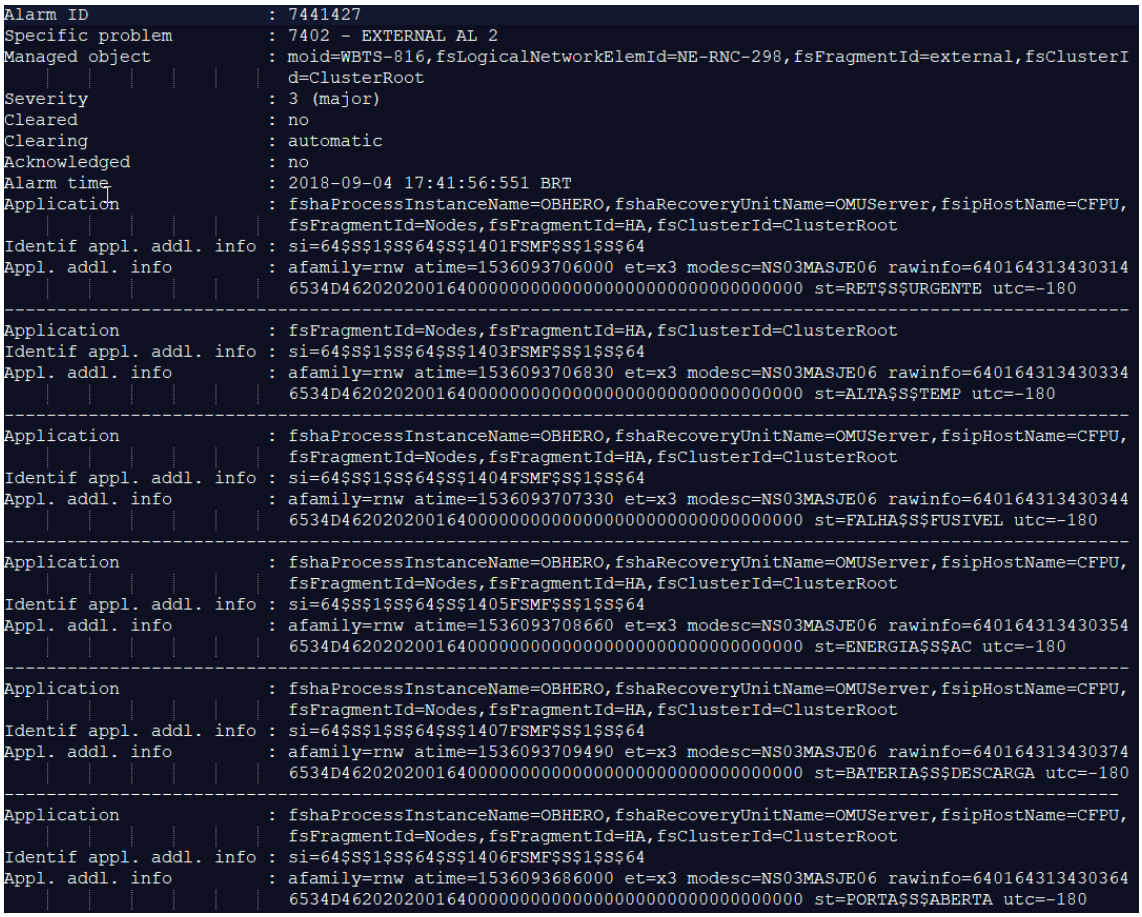


Figure 40 - Alarm Test in RNC source from anonymous

This alarm test is necessary to done, because the telecommunication network provider and network operator can ensure the all alarm are in site and cleaned. This alarm just appears when some of problem appear on site like as:

- ***Rectifier failure***: the "use of rectifiers with constant-power output characteristic is an economic way for avoiding costly over-sizing or a risk of potential system breakdown" (Ascom Energy Syst. Ltd., Berne, Switzerland).
- ***fuse failure:*** in the transmission of information "using optical waveguides, a reduction in the attenuation is associated with a reduction in the transmission losses and with a gain in usable bandwidth and, therefore, with considerable economic advantages, particularly when optical long-distance networks or under Sea cables are involved" (Klein, 2005).
- ***high temperature:*** due to the "growing miniaturization of electronic component, new demand was imposed on the environmental conditions of

the technical equipment. The machine room must be cooled either with simple ventilation in case of low head or by means of actively cooling the air volume used refrigeration machines" (Staefa Control System GmbH, et all).

- ***Ac Failure:*** The present "invention provides a system and method of significantly extending an amount of time that battery power is available to an optical network terminal (ONT) after the AC main power has failed" (Min et al., 2017).
- ***Battery discharge:*** The charge balance "is provided by ion flow between electrodes through an ion-conducting electrolyte. During the discharge process, these processes run backward. In secondary batteries, at least one of the active materials is present in a solid state" (Soloveichik, 2011).
- Open Door: the status of site when the door is opened in base station in certain moment the alarm appears in site.
- ***VSWR major***: A low "VSWR and high efficiency antenna array operating in the band for satellite communications to achieve high radiation efficiency and broad enough bandwidth, all-metal radiation elements and full-corporate waveguide feeding network are employed" (Xiao-Fang, Hua-Zhu, Yi, Shi-Gang, & Sim, 2018).

Modern telecommunication networks may produce "thousands of alarms per day making the task of real-time network surveillance and fault management difficult. Due to the large volume of alarms, network operators frequently overlook or misinterpret them" (Jakobson & Weissman, 1993).

A fault is a disorder "occurring in the hardware or software of the managed network. Faults happen within the managed network or its components. while alarms are external manifestations of faults. Alarms defined by vendors and generated by network equipment are observable by network operators. We are considering only alarms mediated by alarm messages. Similar alarm messages with different time stamps are separate alarms" (Jakobson & Weissman, 1993).

5.2.3. The 4G Integration

The 4G technology came to increase the performance in telecommunication network provider and network operator, therefore the NPO team planning the main plain to include the 2G and 3G in same antenna where each technologies cell radiates with different or the same frequency, this plain has a big advantage in cost reduction of energy and the maintenance can be only in the same place. Although the big disadvantage, is maintenance in hardware and software that requires un expensive cost.

After the planning, the NI team engineer follow the procedure with the excel file to integrate site and also the *XML* file must be run in base station to (provisioned) to associate to all *IPs*, *VLANs*, *VC*, and Mask. This makes the telecommunication increase the performance in 4G add the cells to radiate in the same or different frequency.

The one of the main things to do in integrating site in 4G is to do the adjacency to calculate the handover with other base station this can help the technologies in handover. All this procedure is done remotely with the technical engineer in field to control the functionality, because in some case the site sometime can be down. If the technical engineer does not be in field base station, the integration is not done while the site is not up. And by default, the site always came locked, after the core creation in MSS and the cells must be unlocking manually, if the configuration was well configured and the command was run well, normally in few minutes the site must be on air radiating in base station.

5.3.The Single Radio Access Network

The concept and the commercial reality of the "*Single Radio Access Network* (*Single RAN*) have been around for a few years. Yet such is the potential of the technology to simplify the ever-growing intricacy of the macro radio access layer that it is being developed rapidly and will bring many new benefits for mobile broadband operators" (NSN, 2013).

The SRAN "is simple operating different radio technologies on a single multi-purpose hardware platform. its most developed form, Single RAN will comprise one radio installation with common transport and operational and management system with integrated unified security across *radio access technologies* (*RATs*)" (NSN, 2013).

Modularity is a key enabler, allowing capacity to be scaled up in line with demand, and new and existing spectrum to be used more efficiently. In addition, "operational efficiency can be improved through network sharing, energy efficiency of the radio network will be raised, and software can be used to define the functions of the hardware for ultimate flexibility, performance and cost effectiveness" (NSN, 2013).

Single RAN "is already helping many operators to achieve substantial benefits, but the coming years will see the technology evolving substantially" (NSN, 2013). And the Operators typically expect Single RAN to deliver a variety of benefits, including:

- Efficient use of spectrum and re-farming
- Efficient shared use of hardware
- Smooth evolution of GSM, HSPA and LTE
- Simplified network architecture
- Reduced energy consumption
- Converged planning, operations and management
- Simplified, fully IP-based transport
- Automated 3GPP compliant security
- Lower costs and growth in top line

All these benefits are possible, in re-farming, sharing, modernization and evolution, enabling operators to simplify their networks, reduce costs, grow their business and balance their investments more easily and in better ways.

Single RAN "is focused on simplifying the macro network resulting in lower cost network evolution. That is becoming increasingly important as operators deploy LTE to meet the accelerating mobile broadband boom. It is arguable that LTE was the main trigger for Single RAN as the industry recognized the sheer complexity of adding another radio technology to existing GSM and HSPA layers. Not only is a new radio technology involved, along with a raft of new frequency bands, but IP-based transport needed for LTE must be added to existing ATM and TDM transport links" (NSN, 2013).

Single RAN cuts "through the complexity by running different technologies on one hardware platform, to move from separate installations for each radio technology with its own transport and operational needs, to single installations with a common transport and operational and management system. The Figure 41 shows th Single RAN changing network" (NSN, 2013).

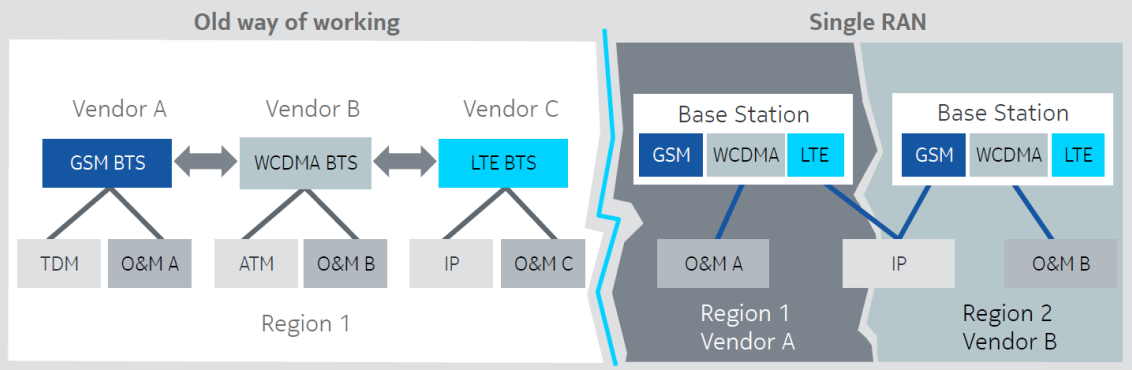


Figure 41 - The Network Changing (NSN 2013)[28]

Technically is complex to "achieve the changing in GSM, HSPA and LTE, because they are distinct technologies, developed independently and standardized separately. Features available in one technology may not be available or applicable for the others." (NSN, 2013).

[28] Imagem retirada do site: https://edoc.site/nokia-single-ran-advanced-evolution-white-paper-pdf-free.html

The "network operators expect that the Single RAN products available since 2008 can be re-used with the latest equipment, *i.e.*, for Re-farming and RF-sharing. This means all three technologies need to be developed in parallel with strong backwards compatibility to maximize the benefits of Single RAN" (NSN, 2013).

Security threats are growing as "operators move to all-IP networks, which require dedicated measures to protect both the infrastructure and end users. There are several sources of security risk, as networks evolve to all-IP open environments and become vulnerable to the kind of attacks familiar from the IT world. As a fully IP technology, LTE creates vulnerabilities not previously seen in GSM and HSPA networks" (NSN, 2013).

The use of IP "transport networks for the backhaul, which are inherently more open than traditional transport networks, means that customer data needs to be protected against eavesdropping. Operator networks must be secured against misuse and other threats, such as denial of service attacks, between the base station and packet core" (NSN, 2013).

Single RAN will have a "key role in helping operators to meet the expected 1000-fold increase in data traffic by providing a clear path for adding macro capacity step-by-step. Typically, operators will have legacy GSM and HSPA base stations and are planning to roll out, or are already rolling out, LTE base stations as well. One of the benefits of Single RAN is that legacy base station equipment can be re-used, *i.e.*, an existing GSM RF module can be re-used in re-farming by GSM-LTE RF sharing, which enables operators to avoid adding LTE RF modules" (NSN, 2013).

Much of the new LTE network "will be focused initially on providing coverage and will comprise sites with three symmetric sectors for simplicity. Capacity-focused sites typically use three asymmetric sectors with some sectors providing greater capacity than others " (NSN, 2013).

Re-farming "some existing GSM frequencies with LTE and HSPA offers great savings and expanded business opportunities for operators, and the actual network rollout is much simpler with Single RAN. In particular, implementing an additional HSPA RF module into the 900 MHz band instead of the 2100 MHz band may reduce

the number of required base station sites by 70%." (NSN, 2013). This translates into a reduction in HSPA base station Capital Expenditure (CAPEX) and Operational Expenditure (OPEX).

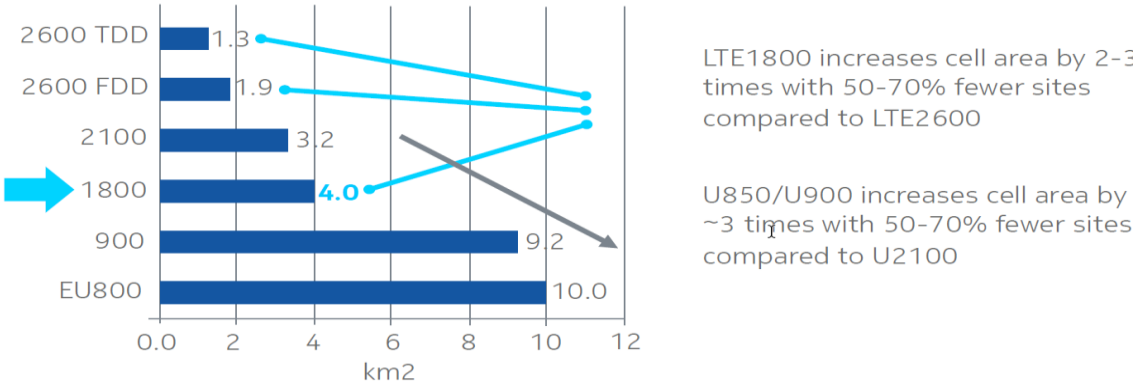


Figure 42 - How the frequency band affects base station site coverage area (NSN 2013)[29]

RF sharing is "enabled by Single RAN base station hardware, in practice changing from *Single Carrier Power Amplifiers* (*SCPA*) in GSM to *Multi Carrier Power Amplifiers* (*MCPA*) as used in LTE and HSPA networks. This opens the door for re-farming because with a simple software upgrade, the existing base station RF can now be used simultaneously for both GSM and LTE, or GSM and HSPA, depending on the frequency

band. HSPA and LTE RF sharing is commercially available today"(NSN, 2013).

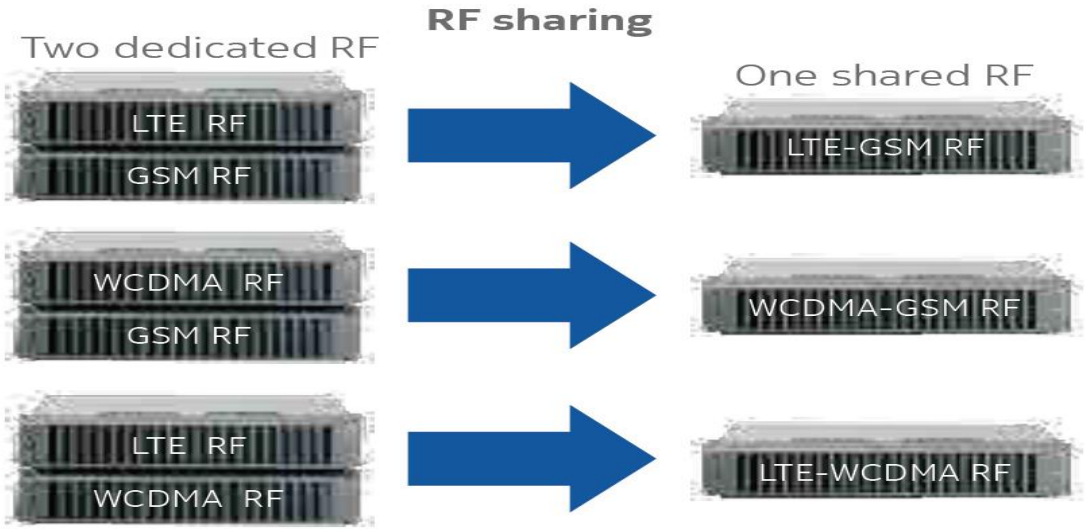


Figure 43 - RF Charing (NSN 2013)[30]

[29] Imagem retirada do site: https://edoc.site/nokia-single-ran-advanced-evolution-white-paper-pdf-free.html

The Figure 50 shows the “support triple sharing, but this has not materialized in commercial networks yet, possibly because the GSM frequency band is typically too narrow or fragmented for triple sharing. When the same spectrum is shared, RF power and front haul transport can have shared by different RF technologies and we can expect these capabilities to develop further in future product generations” (NSN, 2013)..

The Single RAN is the radio network controller function required by GSM and HSPA radio technologies. A multi-controller uses common modular hardware with software-based configurations to meet varying traffic profiles. The Figure 44 shows the Multi-controller scales.

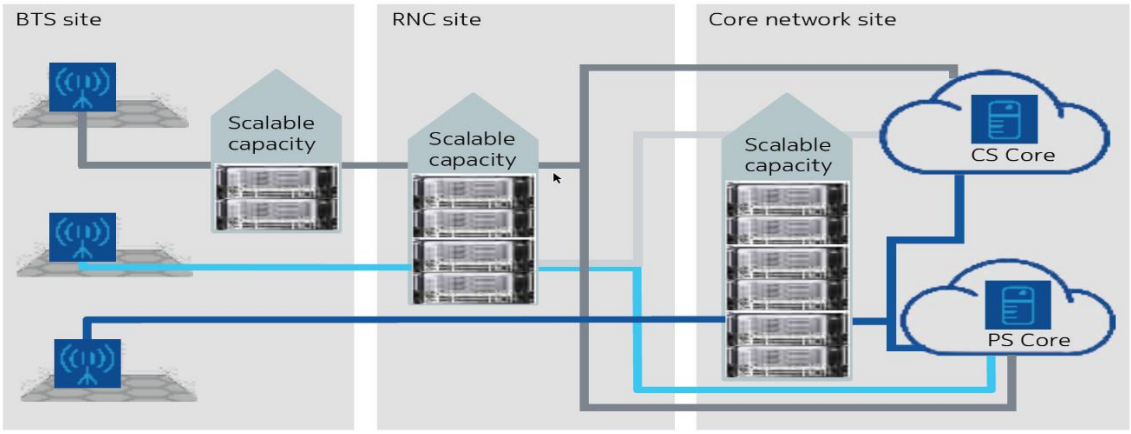


Figure 44 – Multi-controller scales according to location-specific capacity needs (NSN 2013)[31]

As traffic demand” grows, multi-controller capacity can be easily scaled up and with investments in-line with business needs. Similarly, as subscriber usage patterns change over time, the Multi-controller hardware can be readily reconfigured from GSM to HSPA, thereby providing a very straightforward technology migration path and maximizing return on investment” (NSN, 2013).

[30] Imagem retirada do site: https://edoc.site/nokia-single-ran-advanced-evolution-white-paper-pdf-free.html

[31] Imagem retirada do site: https://edoc.site/nokia-single-ran-advanced-evolution-white-paper-pdf-free.html

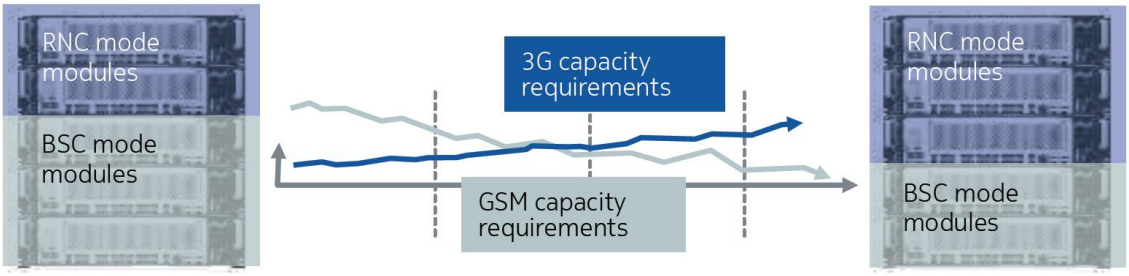


Figure 45 – Multi-controller hardware can be re-purposed for mcRNC functionality (NSN 2013)[32]

Using the latest "multifunctional hardware leads to designs that are far more space efficient than traditional controllers. *I.e.*, typical configurations can handle traditional RNC site capacity with only 70% of capacity being used and in less than 10% of the volume. Ultimately this means that Multi-controllers will be easier to site and cheaper to run than their forebears" (NSN, 2013).

[32] Imagem retirada do site: https://edoc.site/nokia-single-ran-advanced-evolution-white-paper-pdf-free.html

5.4.Technology Performance

To increase the performance and obtain the better result in technologies, is to maintenance and update the equipment, increase the carrier, change type of transmission media (ATM, IUB, DUAL IUB, FULL IP), perform call tests in (MSS) to get the voice data and video traffic in each cells and carrier to help operator to charge the fee and to add performance in (RNC/BSC) controller, perform call alarms (Internal and External) generate by system, BTS/LTE/SRAN configuration, upload licenses and increase power on sites, parameter setting correction, hardware modernization in Radio module and system, configuration in exchange of equipment from a different cell, create and configured the virtual channels interface, create new route in exchange in type of transmission media, delete the all route in exchange in type of transmission media, request and create the adjacency to integrate a new site, create coco in new site in transmission media (ATM), delete coco in exchange of transmission media (ATM to FULL IP), create core in RNC to associate in integration to a new site.

This procedure can help the network operator and telecommunication network provider to increase the performance and to evaluate and analyze the KPI in each technology. During this stage the *GSM UMTS* and *LTE* can provide an overview about they functionalities, *i.e.*, the GSM some time the network operator need to increase the performance, they sometime changing the equipment belong to other vendor (Erickson, Huawei and Nokia), that means the source where the site was radiate must be change and posteriorly delete, this case the deletion is done where the destination is on air with other equipment including performing call and alarm test. The Figures 46 shows the site delete in source and radiate in destination from anonymous operator.

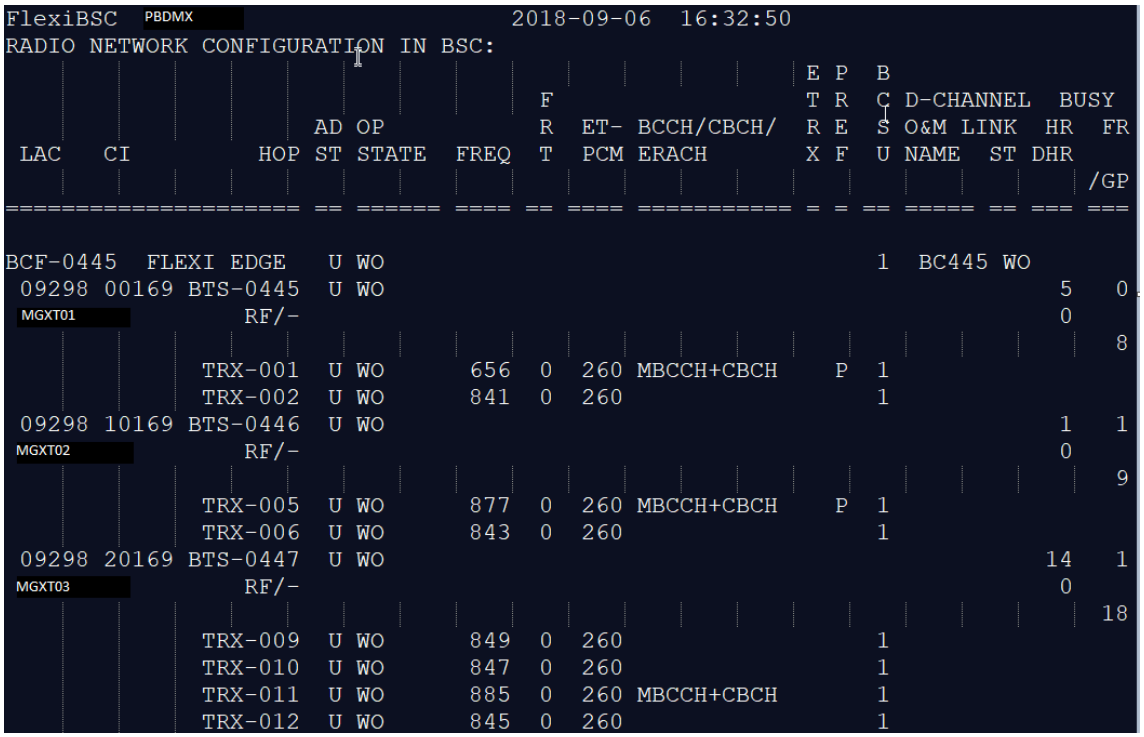


Figure 46 - GSM radiate on destination from anonymous site source from anonymous

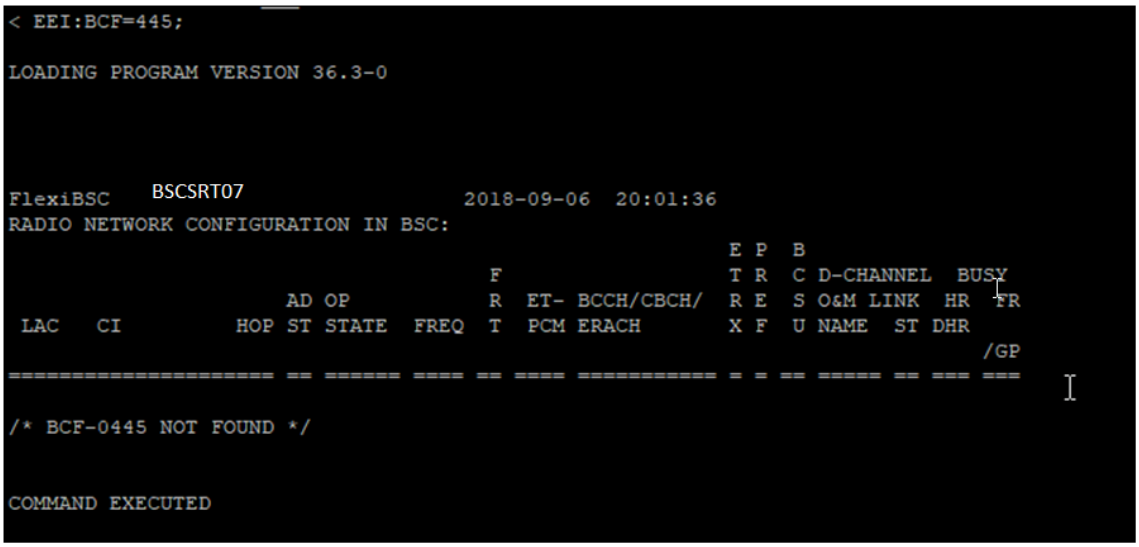


Figure 47 - Deletion of GSM in source from anonymous site

The *UMTS* as a technology with a great capacity and bandwidth than *GSM*, the maintenance requires more effort in update and integrating the new configuration to the transmission media, running route, increase the carrier, performing test call, increase the system module, add frequency, update the licenses, configure the system with new type of site functionality.

The LTE network operator came with purpose of include the all technologies to radiate in the same antenna, but the frequency can be different, this mechanism helps the network operator to increase the performance and reduce the cost in energy supply, and also, makes the maintenance in the same place. But the big disadvantage, is to access the site only one user can access and before the user disconnect than another user can connect. In other word it not multiple user is one user a time.

The one of the better increase of technologies in network operator it`s the *Single RAN* (*SRAN*) inclusion in technology, The SRN as is described in section 5.4, it came to integrate all technology and is demand can be whit multiple user because of IP use this mechanism can help the engineer to result problem easily using IP in any place to access the site.

5.5.The Technologies KPIs Performance Analysis

Considering the technologies performance, after the maintenance in field or remotely, now we can analyze the technologies KPIs to verify in what the network operators can improve or increase to improve the KPIs.

The Figure 48 shows the bar graph representing the Max number of HSDPA user per cell of KPI where the indicator counter shows in each cell has traffic of data provided by Netact tool. This indicator allows the analyze the max intensity of traffic of data in cells in different time as shows in Figure 48 and this intensity can reduce because in certain moment it the call traffic could be reduced.

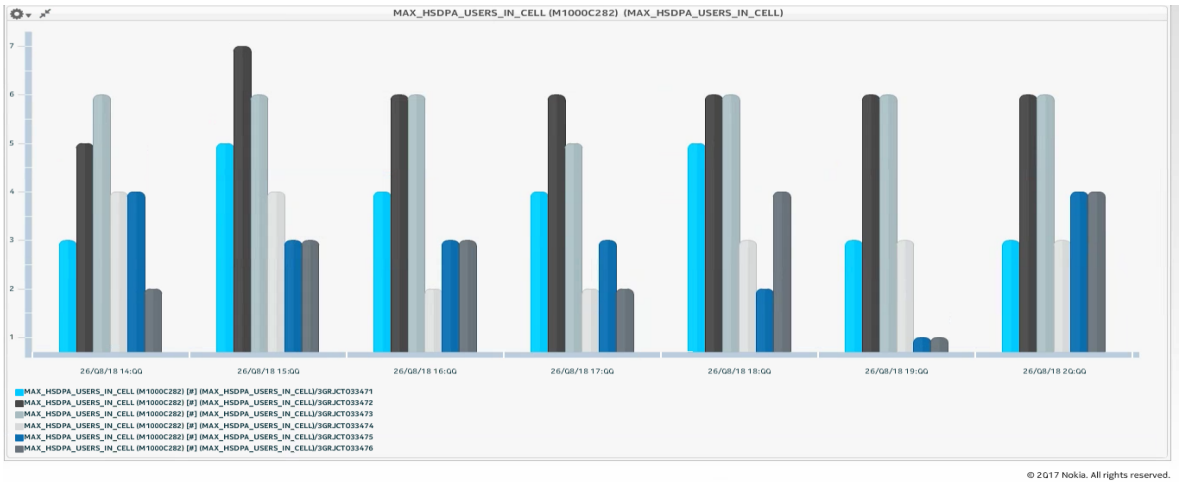


Figure 48 - M1000C282: Max Number of HSDPA Users per Cell source from anonymous

To converging the “different types of networks (run by cellular operators) into one all-IP network is quite appealing. Such a move is not only interesting from the operator’s point of view but will mainly benefit the users. Running all services over IP has the potential to facilitate a mix of services from each terminal, *e.g.*, talking, showing pictures to one or more persons while at the same time downloading e-mail”(Ericson, Wanstedt, & Pettersson, 2006).

The high-quality voice over CS “usually has an end-to-end delay of no more than 220 ms, speech frame losses of less than 2% (the sum of UL and DL) and almost no delay jitter at all. The Figure 49 shows that the traffic rate for Rab Setup Completions for Cs Voice flame is measured in accordance with the size of the data rate traveling at a

particular base station in order to cover and increase a high rate of data traffic in a call in anytime to evaluate or analyze the KPI performance in cells"(Ericson et al., 2006).

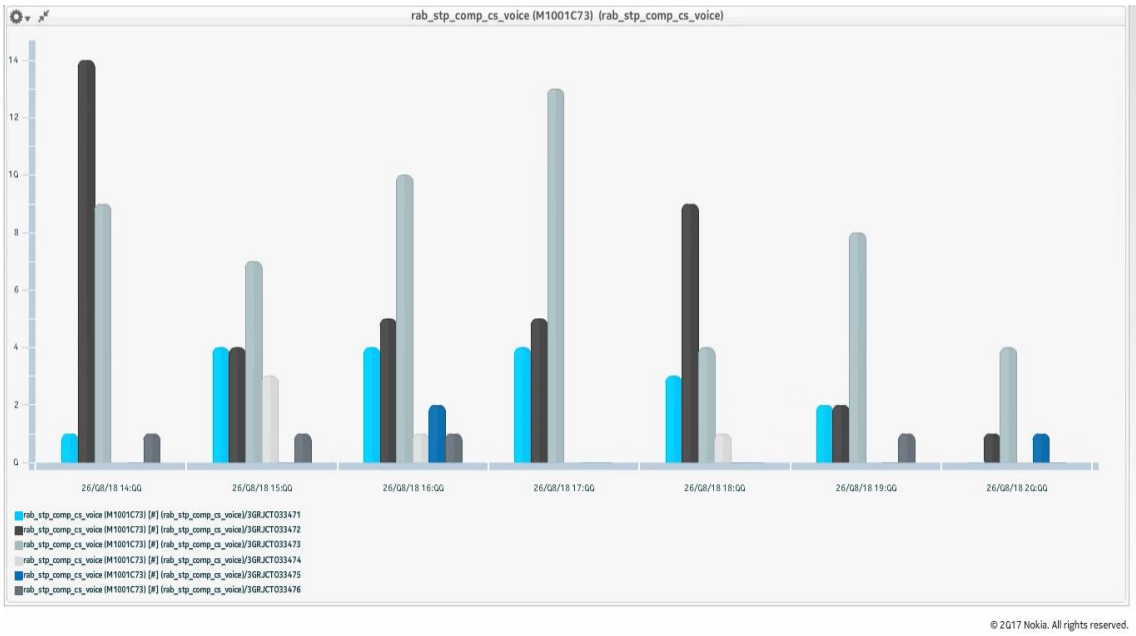


Figure 49 - M1001C73: Rab Setup Completions for Cs Voice source from anonymous

One of the key services, in a migration from CS to PS, is voice, "since voice is the by far most important of all cellular services today. Hence, PS voice (or Voice over IP, VoIP) over cellular, in some basic mode, must provide a speech service with the same reliability, quality, and coverage that cellular users have become accustomed to. With the advent of HSDPA/EUL for WCDMA the necessary transport infrastructure for PS services will be available" (Ericson et al., 2006).

The Figure 50 shows that the traffic rate for Rab Setup Completions for PS Data Intra where is measured in accordance with the size of the data rate traveling at a particular base station in order to cover and increase a high rate of data traffic in a call in anytime to evaluate or analyze the KPI performance in cells.

To reach competitive efficiency with PS voice over HSDPA is not just a matter of optimizing the radio network performance; all nodes in the chain must be involved.

Important areas for high PS voice capacity are:

- Protocol overhead: adding IP/UDP/RTP headers to speech frames results in "an overhead ratio of about 60-70% (header: 30 to 60 bytes; payload: 32 bytes for AMR12.2). Using header compression (ROHC) this ratio can be

reduced to less than 10% (header: typically, 3 or 4 bytes)" (Ericson et al., 2006).

- Scheduling: Access to the HSDPA channel is "distributed over time by a scheduler, with priority usually based on radio conditions or bit rate. To use the radio optimally, *i.e.*, to make sure that base station (BS) does not have to transmit in the deepest fading dips, the scheduler must be allocated sufficient time. Time for scheduling has to be limited given the delay constraint for conversations" (Ericson et al., 2006).
- Delay and jitter: Scheduling and retransmissions add delay and jitter to the packet stream, *i.e.*, the UE must be able to handle the jitter efficiently.
- Power overhead: Minimizing the power usage of the control channels is very important for good VoIP capacity. One remedy for this is the introduction of fractional DPCH instead of A-DPCH.

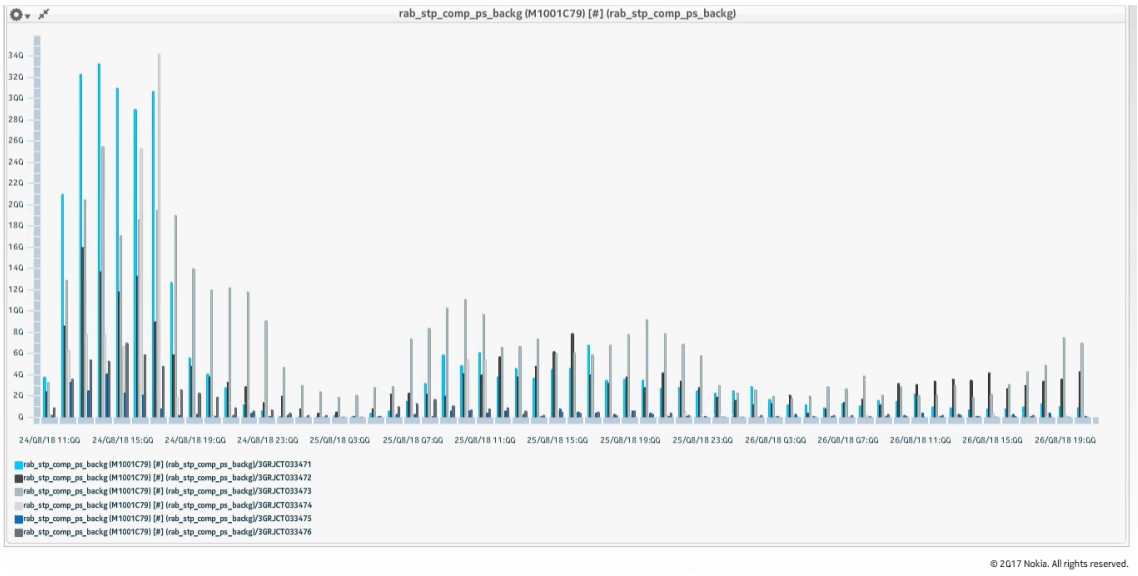


Figure 50 - M1001C78: Rab Setup Completions for PS Data Intra source from anonymous

In the literature, most works have used discrete event simulation to "evaluate the performance of HSDPA, were the first to consider the interaction between queuing at the data link layer and AMC at the physical layer, in an analytical model. However, their analysis assumed Poisson arrivals at the data link layer and did not explicitly account for HSDPA. Moreover, we are aware of no work to date that attempts to quantitatively compare HSDPA user equipment (UE) categories." (Ericson et al., 2006).

The problem is highly challenging, since we have to take into account a number of factors and characteristics such as:

- the bursty and correlated nature of the packet-traffic through the channels,
- channel conditioning which is often represented by Channel Quality Indicator (CQI),
- dynamic allocation of channels by a preset physical channel assignment scheme, and
- packet-losses in the air interface due to fading channels.

In the implementation of "HSDPA, several channels are introduced Figure 51. The transport channel carrying the user data, in HSDPA operation, is called the High-Speed Downlink Shared Channel (HS-DSCH). The High-Speed Shared Control Channel (HS-SCCH), used as the downlink (DL) signaling channel, carries key physical layer control information to support the demodulation of the data on the HS-DSCH." (Ericson et al., 2006).

The UE "calculates the DL Channel Quality Indicator (CQI) based on the received signal quality measured at the UE throughput. Then, it sends the CQI on the HS-DPCCH channel to indicate which estimated transport block size, modulation type and number of parallel codes (i.e. physical channels) could be received correctly with reasonable block error rate in the DL. The CQI is integer valued, with a range between 0 and 30. The higher the CQI is, the better the condition of the channel and the more information can be transmitted" (Do et al., 2014).

The one of others KPIs it`s the Netact, that I frequently use this help us to increase and analyze the KPIs using the methodology for network mobile configuration to evaluate in:

- capacity to analyse, the "performance which allow to calculate the capacity offered in the cell to communications services, which are supported in mobile

mode communications in different service like Voice Services, Short Message Services (SMS), Data Services" (Do et al., 2014).

- The coverage, to provide the mobility to mobile communication system in technology to provision of high-performance data transmission services such as internet access services and multimedia services. The "KPIs verification to reach the high quality of signal to determine the maximum connection distance allowed to calculate the maximum attenuation enabled, for transmission and reception in frequency distribution and the PCI`s, to improve the quality of services, network performance, network availability and accessibility, service accessibility, integrity and maintenance" (Do et al., 2014).

The Netact KPI it's good to analyse the capacity, the coverage to provide the mobility to mobile communication system in different technologies (GSM, UMTS an LTE) and it also help us building the graph. The Figure 51 is to reach an anonymous operator to show the KPI performance evaluation.

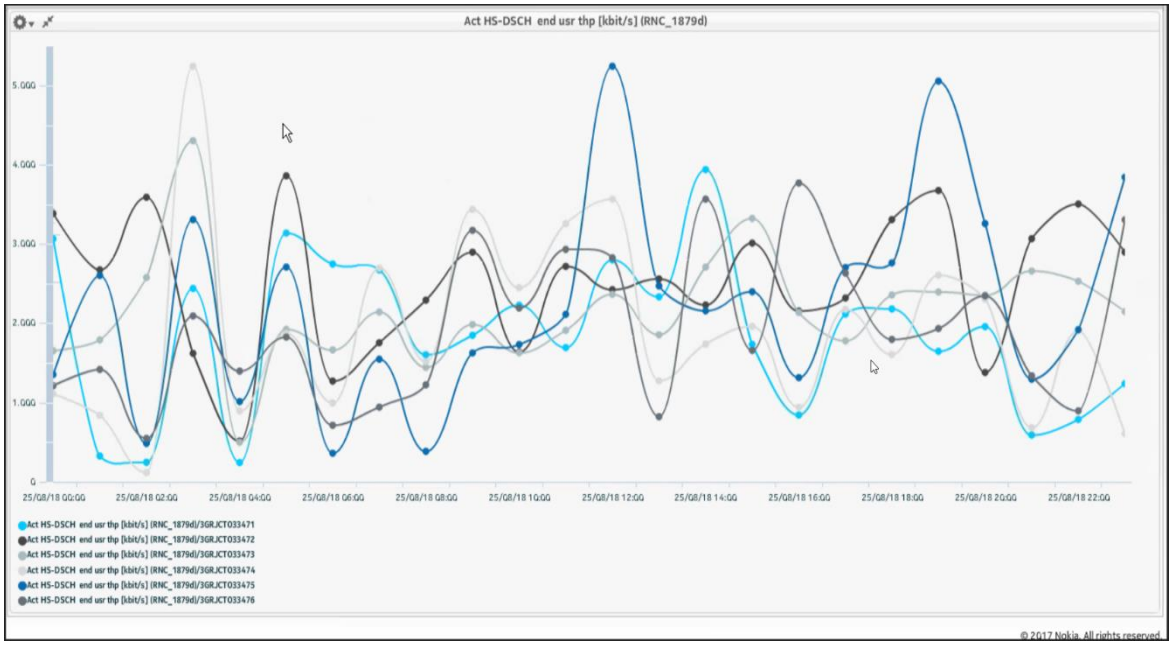


Figure 51 - Act HS-DSCH end user thp [kbits/s] [RNC_1879d] source from anonymous

Handover[33] is the mechanism that transfers an ongoing call from one cell to another as a user moves through the coverage area of a cellular system. As "smaller cells are deployed to meet the demands for increased capacity, the number of cell

[33] The terms "handover" and 'Randoff" are used interchangeably within the literature

boundary crossings increases. Each handover requires network resources to reroute the call to the new base station. Minimizing the expected number of handovers minimizes the switching load. Another concern is delay. If handover does not occur quickly, the QoS may degenerate below an acceptable level. Minimizing delay also minimizes co-channel interference" (Pollini, 1996).

During the handover there is a brief service interruption. As the frequency of these interruptions increases the perceived QoS is reduced. The "chances of dropping a call due to factors such as the availability of channels increase with the number of handover attempts. All of these issues place additional challenges on the cellular system. As the rate of handover increases, handover algorithms need to be enhanced so that the perceived QoS does not degenerate and the cost to the cellular infrastructure does not skyrocket"(Pollini, 1996). Much effort is being expended to study existing handover schemes, and to create new ones that meet these challenges.

The performance metrics used to evaluate basic performance aspects of handover algorithms like as:

- *Call blocking probability* -the probability that a new call attempt is blocked;
- *Handover blocking probability* - the probability that a handover attempt is blocked;
- *Handover probability* - the probability that, while "communicating with a particular cell, an ongoing call requires a handover before the call terminates. This metric translates into the average number of handovers per call with the Soft HO Success Rate as the Figure19 shows"(Pollini, 1996);
- *Call dropping probability* - the probability that "a call terminates due to a handover failure. This metric can be derived directly from the handover blocking probability and the handover probability" (Pollini, 1996);
- *Probability* of *an unnecessary handover* - the probability that "a handover is stimulated by a particular handover algorithm when the existing radio link is still adequate" (Pollini, 1996);
- *Rate* of *handover* - the number of handovers per unit time. Combined "with the average call duration, it is possible to determine the average number of handovers per call, and thus the handover probability" (Pollini, 1996);

- *Duration* of *interruption* - the length of time during a handover for "which the mobile terminal is in communication with neither base station. This metric is heavily dependent on the particular network topology and the scope of the handover" (Pollini, 1996);
- *Delay* - the distance "the mobile moves from the point at which the handover should occur to the point at which it does" (Pollini, 1996).

The line graph of Figure 52 can help us to analyze the KPI behaviors, where "this feature enables direct mobility from the *High Speed Dedicated Signalling Channels (HS- DSCH*) in one cell to the HS- DSCH in another cell is to represent the cell KPIs. DSCH

The HSDPA Serving Cell Change is a HS- DSCH to HS- DSCH HO that can happen either:

- intra-BTS intra-RNC or
- inter-BTS intra-RNC

The main input for selecting the serving cell are periodical UE's intra-frequency measurement reports for the quantity CPICH Ec/N0" (Holma et al., 2009).

The operator can control the sensitivity of the serving cell change. For all cases, the MAC-hs of the source cell is reset upon the serving cell change and the RLC protocol takes care of the retransmission of the data to the target cell.

This feature provides the operator with better performance since the best available radio condition in the active set is used for HS- DSCH.

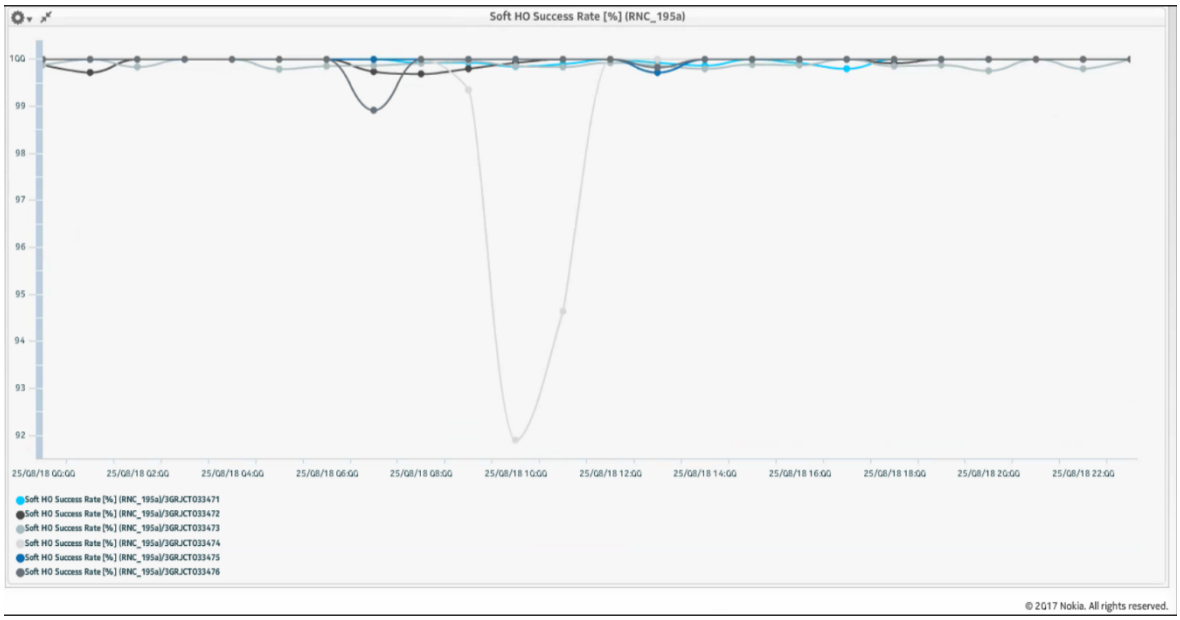


Figure 52 - Soft HO Success Rate [%] [RNC_195a] source from anonymous

This feature provides "*High Speed Downlink Packet Access (HSDPA)* service in the whole cell coverage area and between the cells.

Soft/Softer Handover (HO) for HSDPA users enables HSDPA usage in the whole cell coverage area and between the cells. The following intra-frequency soft/softer HOs for associated *Dedicate Packet Channels (DPCH)* are supported

- Intra-BTS intra-RNC softer handover;
- Inter-BTS intra-RNC soft handover;
- Inter-BTS inter-RNC soft handover

Implementation of the above-mentioned HOs ensures full coverage for HSDPA. Therefore, HS- DSCH is also supported for UEs with an active set size larger than one (to the UEs in the *Soft Handover (SHO)* region)" (Holma et al., 2009).

The table 10 of cell availability inform the result obtained in this research:

Table 10 - The KPI Service Rate for Mobile Telecommunication Network (Holma 2009)[34]

Service Category	RRC Access Ratio network	RAB Access Ratio for Voice Calls	RAB SR Voice	Total CS traffic - Erl
Voice	91.81	100.00	99.63	0.08
Massages	89.23	99.64	99.31	0.05
Browsing	94.01	99.77	9858	1.60
information	98.03	99.81	99.49	0.13
Personalization	97.78	97.44	99.50	0.09
Game	96.35	88.18	99.82	0.57
Video demand	54.91	72.22	99.43	0.38
Music	27.47	70.18	99.16	0.32
Mobile data Networking	23.00	66.92	99.21	0.95

The table represent the services categories results obtained in research:

- The voice ratio for current environment in real time;
- The massages rate for SMS, e-mails Photo massages;
- Browsing the rate of access, the information services online, for which users pay standard network rates. Currently limited to WAP browsing over GPRS and 3G networks;
- Information Content the rate of information for users to get basic information network;
- Personalization predominantly ringtones, rate and includes screensavers and ring backs;
- Game the rate of downloadable and online games;
- Video demands the streamed content and video downloadable rate;
- Music the full track downloads and analogue radio services rate.

[34] Imagem retirada do site: https://books.google.pt/books?id=uhr3KwSww2kC&pg=PA252&lpg=PA252&dq=hs-dsch+throughput&source=bl&ots=qgBDCYa1cE&sig=wvppLKZCcZ9q7h57g2Ckn8u1LUo&hl=pt-PT&sa=X&ved=0ahUKEwiz49f7p67YAhWPCuwKHchNCeIQ6AEIQTAD#v=onepage&q=hs-dsch throughput&f=false

Mobile data network the corporate access rate, intranets, databases, as well as the use of application such as CRM.

5.6.The Technologies Result

In this stage shows the result in technologies, were they are radiate in each base station that makes the network operator ensure that each site is radiate normally, and also, they can monitor the site remotely to control the status on air using the application appropriate.

The 2G sites can be monitored by two ways, by shell command prompt where the engineer can run the command to shows the site status working. The Figure 53 shows the 2G shell command prompt status

```
< ZEEI:BCF=445;

LOADING PROGRAM VERSION 36.3-0



FlexiBSC  BSCRD35                    2018-09-06  16:32:50
RADIO NETWORK CONFIGURATION IN BSC:
                                                    E P  B
                                          F         T R  C D-CHANNEL  BUSY
                      AD OP               R  ET-  BCCH/CBCH/  R E  S O&M LINK  HR  FR
 LAC   CI         HOP ST STATE   FREQ     T  PCM  ERACH       X F  U NAME   ST DHR
                                                                              /GP
==================== == ====== ==== == ==== ========== = = == ====== == === ===

BCF-0445  FLEXI EDGE   U WO                                    1  BC445 WO
 09298 00169 BTS-0445  U WO                                                5   0
 NKDPS1123       RF/-                                                      0
                                                                             8
             TRX-001   U WO      656  0  260 MBCCH+CBCH    P  1
             TRX-002   U WO      841  0  260                  1
 09298 10169 BTS-0446  U WO                                                1   1
 NKDPS1124       RF/-                                                      0
                                                                             9
             TRX-005   U WO      877  0  260 MBCCH+CBCH    P  1
             TRX-006   U WO      843  0  260                  1
 09298 20169 BTS-0447  U WO                                               14   1
 NKDPS1125       RF/-                                                      0
                                                                            18
             TRX-009   U WO      849  0  260                  1
             TRX-010   U WO      847  0  260                  1
             TRX-011   U WO      885  0  260 MBCCH+CBCH       1
             TRX-012   U WO      845  0  260                  1
```

Figure 53 - 2G Status in Sell Command Prompt source from anonymous

After it the engineer also, can verify the data, voice and video traffic in each BTS channels of frequency like we can see in Figure 53 in channel of 656, the HR call is 5 rate of call voice and video pass in this channel, in the same channel With FR data traffic pass also with value 8. In channel of 877, the HR call is 1 rate of call voice and

video pass in this channel, in the same channel With FR data traffic pass also with value 1. And in channel of 885, the HR call is 14 rate of call voice and video pass in this channel, in the same channel With FR data traffic pass also with value 18.

In the graphical interface we also can see the data traffic in BTS, the Figure 54 shows the 2G BTS status.

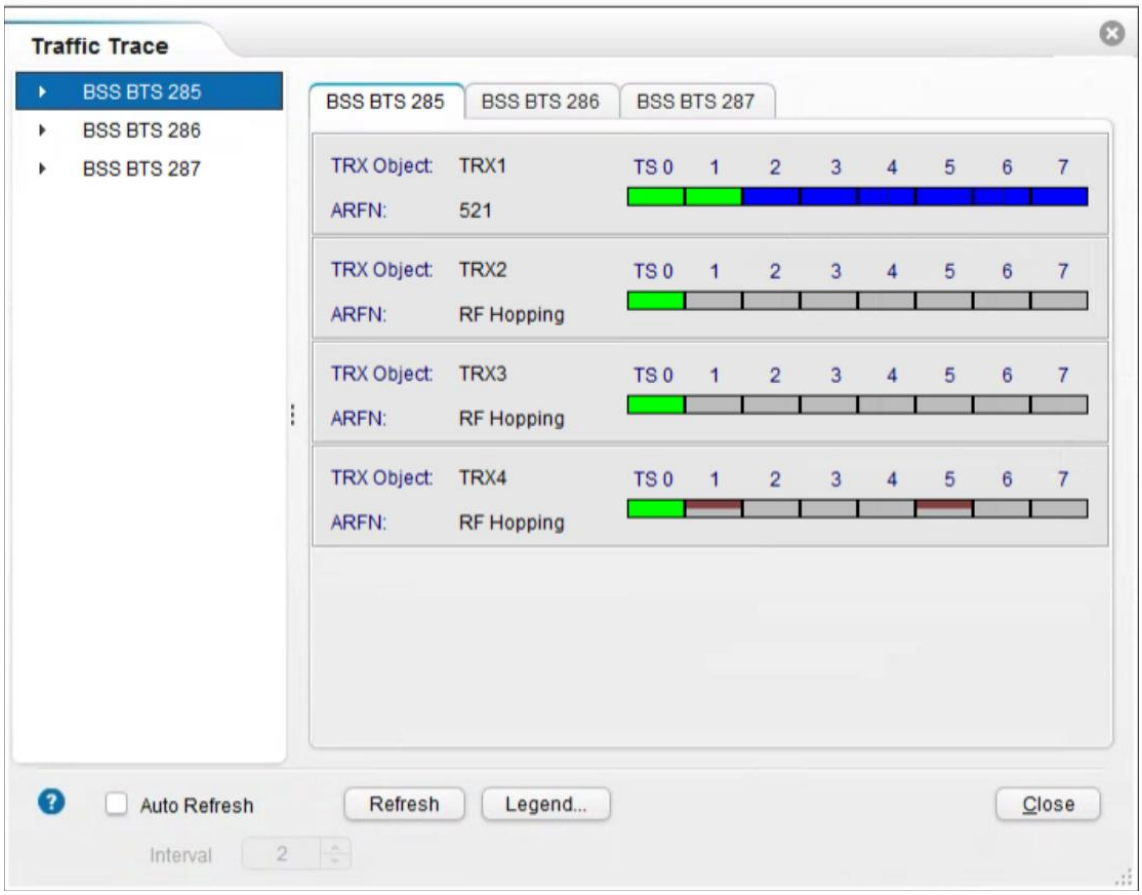


Figure 54 - 2G BTS Graphical Interface Status source from anonymous

The Figure 54 shows the BTS 285 radiating where in channels 1 and 5 pass the data traffic represented by brown color.

The 3G sites can also be monitored by two ways, by an application where the engineer can view the site status, to shows the site status working. The Figure 55 shows the 3G site status in an application.

WBTSId	WBTSName	WCELId	CellAdditionalInfo	CId	WCELMCC	WCELMNC	CellType	WCelState	Hig...	HSDPAenabled	HSDPAcapability	HSDSCHOpState	LAC
890	3GDPKS0890	627		627	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	628		628	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	629		629	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	8904		8904	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	8905		8905	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	8906		8906	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600
890	3GDPKS0890	38907		38907	724	31	Not_defined	WORKING		Enabled	HSDPA capable	Enabled	3600

Figure 55 - The 3G site status (Holma 2009)[35]

The Figure 55 shows the site status radiating with cells are with *WORKING* status in wcell State. This mechanism can help the engineer to know if soothing was wrong with site. And the Figure 56 shows the 3G site radiating in graphical interface.

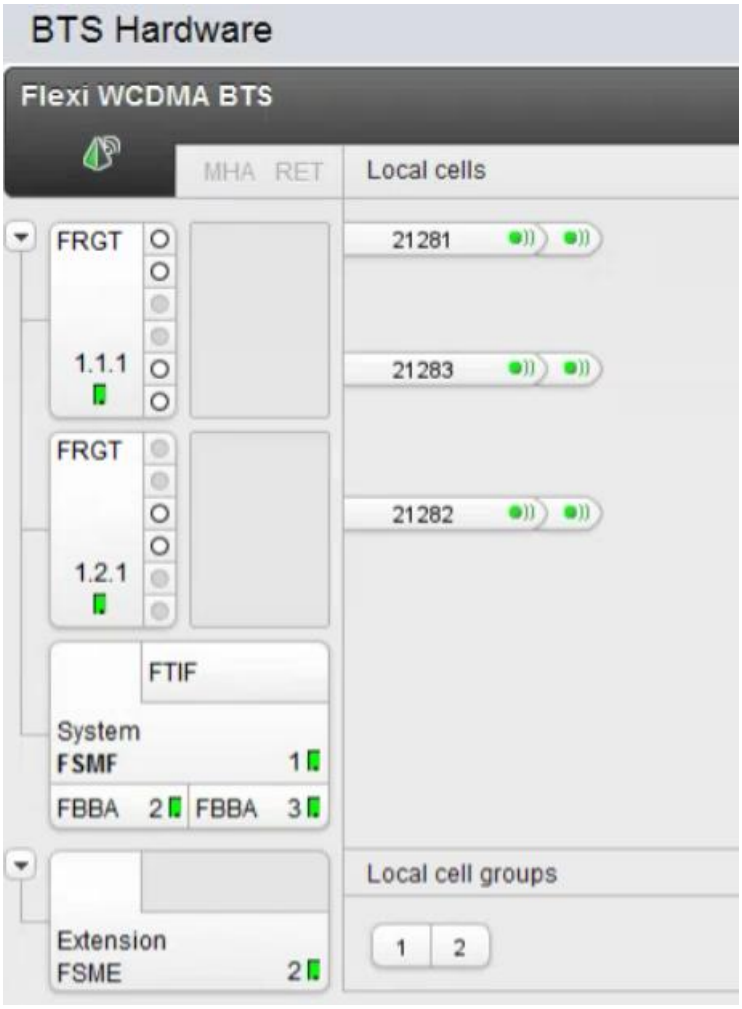


Figure 56 - The 3G Graphical Interface source from anonymous

The Figure 56 shows the 3G graphical interface, where the cells is radiating normally with three sectors two carrier and 6 cells. In each cell has is cell Id radiating, the green color means the cells is on air. In the left side has two *FRGT* system modules, this module helps the site in performance and frequency in site cells, unlike the 2G has ETH where it is responsible to transfer the information in BSC communication with BCFs and BTSs. In left side also has the extension module, that makes the network operators the increase the performance adding this extension module, this help them to

[35] Imagem retirada do site: http://www.personalizemedia.com/virtual-worlds-web-30-and-portable-profiles/

add carrier and cells to increase the quantity of user numbers in site, add frequency and capacity in site to cover the certain distant of area in call on the site.

The LTE also use the same application and the site has same graphical interface, but the configuration is different as LTE came to increase the performance in network operators using IP packet and include the 2G and 3G technologies in the same antenna to reduce the cost, but they work separately and the access in graphical interface can be possible only with single user not multiple user, if the other user want get access on the site the other user must disconnect of site to give the access to other user this mechanism it use for who are connect in local area or remotely are the same procedure. This mechanism style impacts the efficiency on sites.

The one of best improvement in network operator system is the arrival o Single RAN, the SRAN helps the networks to increase the efficiency in site functionality including the 2G and 4G to integrate on SRAN. With SRAN allow the users get multiple access because the SRAN use IP where any one can access if you have the credential login user and password to authenticate on site.

The SRAN also has its version in which it radiates, the version 16 has it graphical interface and it also as version 17 with it interface, where they have different in graphical interface. The Figure 57 and 58 shows the graphical interface of version 16 and 17.

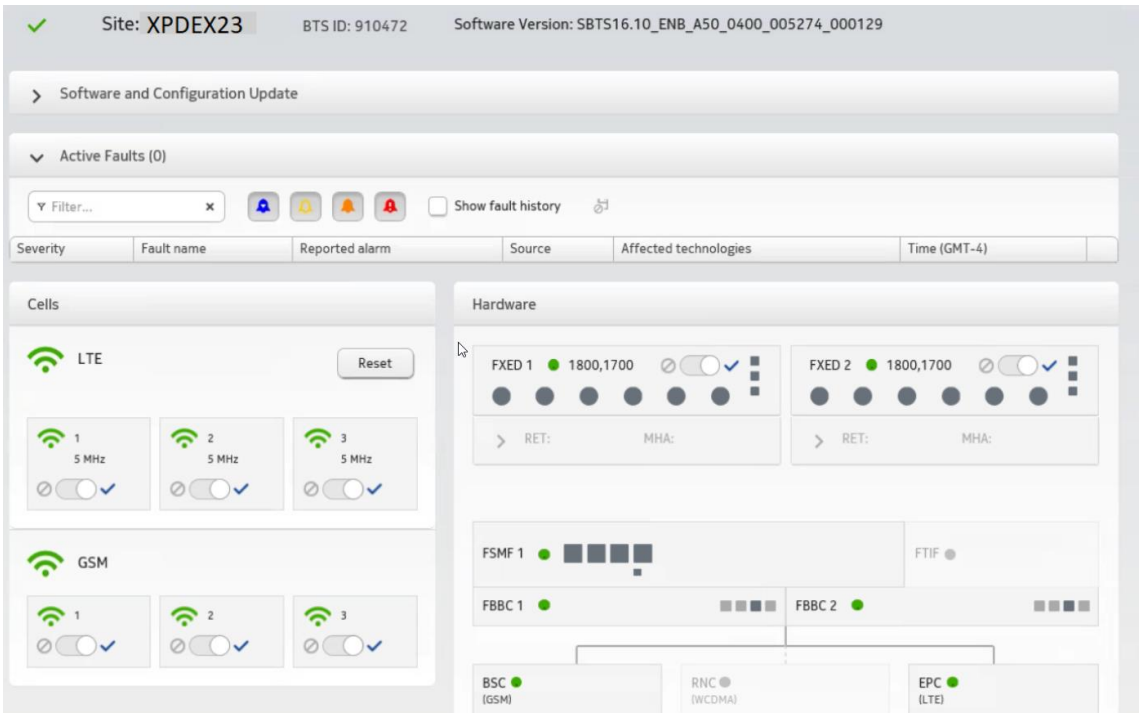


Figure 57 - Single RAN Version 16 source from anonymous

The Figure 57 shows the SRAN version 16.10 where we have the *LTE* and *GSM* are integrated and are radiating normally with each technology has is frequency is radiating on top we can see the site name the *BTS* id and the site version also, I the middle the types of alarms the can appear on site if the alarm is on site. The left side the cells are radiating in *LTE* and *GSM*, in right side the Hardware equipment with the system module, if we can see on down in right side we can see the connection between the *BSC* (*FBBC1*) and LTE like a bridge (FBBC1 and FBBC2).

Figure 58 - Single RAN Version 17 source from anonymous

The Figure 58 Shows the Single Ran version 17 where its interface has many modifications shows the fan controller and fan group, the system module, cabinet 1 and 2 cable connection whit cells, BTS Mediator and so on.

To conclude in this dissertation, this project is a more increase and help in my Knowledge in telecommunication Network area. The research and development about this thesis were a great improvement to my knowledge telecommunication area in Optimization of the methodology of mobile communication Network and automatized system.

CHAPTER 6 – CONCLUSIONS AND FUTURE WORK

" Wherever you are, this is your starting point."
(Kabir)

This chapter concludes with the following section:

- ***Section 1:*** Present the main conclusion and questions and answers of this project. What the improvement to this project.
- ***Section 2:*** The future work to telecommunication network provider and network operator.

6.1 The Main Conclusions

The main conclusion is the task of completing a thesis dissertation is of great difficulty, because as we deepen our studies, the acquired knowledge becomes capable of opening doors that were previously inaccessible to our thinking. In this small paragraph with the following reflection it said: "*The mind that opens itself to a new idea will never return to its original size*." (*Albert Einstein*).

During the entire phase of this master's project, we highlight the experience acquired, mainly in the construction of a Graphical Interface for the automated system and in the research of how to improve the time and unfolding optimization and configuration of a telecommunication network, that is target the master of this master's project. And also, the study on the theoretical knowledge of the computational approach on telecommunication network was of great relevance and essential for the good understanding and development of this master’s project. From this, I conclude that the theoretical foundation acquired was an important step to start this project and of great value to help the way of this project.

All this knowledge served as a foundation, that is, it was sufficient to successfully support and track the automated system. But it is also important to emphasize the technical and theoretical concepts learned outside the university, because the university reveals the tools and the student builds its path.

This thesis present *Optimization of the methodology of mobile communication Network and automatized system,* that permit a significant increase in mobile communication network technologies. In this thesis we provide the research problem to answer the questions such as,

- What`s the difference between planning and operating a communication system using the technologies (GSM UMTS and LTE)? The planning is integrating part of process to put communication system of technologies in operating;
- What is the decision criterion for implementing the technologies (GSM UMTS and LTE)? To have network scalable, we need to have a good infrastructure, quality equipment, always it necessary to change the media transmission to increase performance and IP data service to support the operator`s necessity;
- What the analyze criterion for implementing the technology GSM UMTS and LTE)? To answer this question is important to understand what kind of Analyze we want Analyze, in quality, cost, capacity term or implementation time. All these terms have been analyzed. *E. g*, the quality term, we can calculate how to reach the signal in base station to a certain coverage area, and what`s the cost level to spend with resource, what quality of hardware capacity to support that infrastructure to be deployed and what does the implement time need to finish the service;
- What are the most important KPIs for characterizing system performance? To answer this question, it's important to know that KPI system overview in focus on the radio network performance, (*e g, Accessabillity, Retainability, Mobility, Availability, Utilization,* and *Traffic*). And other focus is on the user experience (*e. g, Latency* and *Integrity*). "The KPI also can be used to evaluate the intra-frequency handover out success rate in cell or cluster, evaluate the inter-RAT handover success rate from LTE to WCDMA and CDMA2000 in a cluster" (KPI in LTE Radio Network n.d.);
- What possible setting to make on base station? In this answer, we need to know hardware capacity. *E g,* number of sectors in a certain base station, deploy MIMO technology, to improve of reception in a single cell site, antenna powers to reach high quality of signal to make handover;

- What methodology should be used to optimize the base station configuration? A base station can be optimized mainly in 3 points. In network capacity or resource available level, in coverage area level and infrastructure cost level. All this level needs to be studied deeply to optimize a base station;
- What methodology of optimization is possible to following? To following methodology optimized, we need to define a plan to calculate what quality, cost capacity and implement time we should estimate to avoid poor project quality.

Among the constraints of a work time is one of these factors, and therefore in the proposal phase of this project, this dimension was also considered. Therefore, the future work related to the 5G is discussed in next section.

6.2 Future Work

As future work is to explore the previous four generations of cellular technology have each been a major paradigm shift that has broken backwards compatibility. The fifth generation (5G) of mobile network communication system, in just the “past year, preliminary interest and discussions about a possible 5G standard have evolved into a full-fledged conversation that has captured the attention and imagination of researchers and engineers around the world. As the long-term evolution system embodying 4G has now been deployed and is reaching maturity, where only incremental improvements and small amounts of new spectrum can be expected, it is natural for researchers” (Andrews et al., n.d.).

In just “a decade, the amount of IP data handled by wireless networks will have increased by well over a factor of 100: from under 3 Exabyte’s in 2010 to over 190 Exabyte’s by 2018, on pace to exceed 500 Exabyte’s by 2020. This deluge of data has been driven chiefly by video thus far, but new unforeseen applications can reasonably be expected to materialize by 2020.The 5G sheer volume of data, the number of devices and the data rates will continue to grow exponentially. The number of devices could reach the tens or even hundreds of billions by the time 5G comes to fruition, due to many new applications beyond personal communications” (Andrews et al., n.d.).

The engineers of network telecommunication have they duty “with these intense demands via innovative new technologies that are smart and efficient yet grounded in reality. Academia is engaging in large collaborative projects such as METIS and 5G NOW, while the industry is driving preliminary 5G standardization activities” (Andrews et al., n.d.).

In order to understand the engineering challenges more concretely facing 5G technologies “like ultra-densification, mm Wave, and massive multiple-input multiple-output (MIMO), and to plan to meet them, it is necessary to first identify the requirements for a 5G system. The following items are requirements in each key dimension, but it should be stressed that not all of these need to be satisfied simultaneously” (Andrews et al., n.d.).

Different applications will place “different requirements on the performance, and peak requirements that will need to be satisfied in certain configurations are mentioned below. For example, very-high-rate applications such as streaming high-definition video may have relaxed latency and reliability requirements compared to driverless cars or public safety applications, where latency and reliability are paramount but lower data rates can be tolerated” (Andrews et al., n.d.).

The data rate needs to support the mobile data traffic explosion is unquestionably the main driver behind 5G. Data rate can be measured in several different ways, and there will be a 5G goal target for each such metric:

a) Aggregate data rate refers “to the total amount of data the network can serve, characterized in units of bits/s/area. The general consensus is that this quantity will need to increase by roughly 1000x from 4G to 5G” (Andrews et al., n.d.).
b) Edge rate, or 5% rate, “is the worst data rate that a user can reasonably expect to receive when in range of the network, and so is an important metric and has a concrete engineering meaning. Goals for the 5G edge rate range from 100 Mbps (easily enough to support high-definition streaming) to as much as 1 Gbps. Meeting 100 Mbps for 95% of users will be extraordinarily challenging, even with major technological advances. This requires about a 100x advance since current 4G systems have a typical 5% rate of about 1 Mbps, although the precise number varies quite widely depending on the load, cell size, and other factors” (Andrews et al., n.d.) .
c) Peak rate is the best-case data “rate that a user can hope to achieve under any conceivable network configuration. The peak rate is a marketing number, devoid of much meaning to engineers, but in any case, it will likely be in the range of tens of Gbps. Meeting the requirements in (a)-(b), which are about 1000x and 100x current 4G technology” (Andrews et al., n.d.).

The latency current 4G roundtrip latencies “are on the order of about 15 ms and are based on the 1 ms subframe time with necessary overheads for resource allocation and access. Although this latency is sufficient for most current services, anticipated 5G applications include two-way gaming, novel cloud-based technologies such as those that

may be touchscreen activated (the “tactile Internet”), and virtual and enhanced reality (e.g., Google glass or other wearable computing devices). As a result, 5G will need to be able to support a roundtrip latency of about 1 ms, an order of magnitude faster than 4G” (Andrews et al., n.d.)

The energy and cost, as we move to 5G, “costs and energy consumption will, ideally, decrease, but at least they should not increase on a per-link basis. Since the per-link data rates being offered will be increasing by about 100x, this means that the Joules per bit and cost per bit will need to fall by at least 100x. For example, mmWave spectrum should be 10-100x cheaper per Hz than the 3G and 4G spectrum below 3 GHz. Similarly, small cells should be 10-100x cheaper and more power efficient than macrocells. A major cost consideration for 5G, even more so than in 4G due to the new BS densities and increased bandwidth, is the backhaul from the network edges into the core” (Andrews et al., n.d.).

References

Al-Gizawi, T., Peppas, K., Axiotis, D. I., Protonotarios, E. N., & Lazarakis, F. (2005). Interoperability criteria, mechanisms, and evaluation of system performance for transparently interoperating WLAN and UMTS-HSDPA networks. *IEEE Network*, *19*(4), 66–72. https://doi.org/10.1109/MNET.2005.1470685

Al-shamisi, H. S., Al-shamisi, H., Kostanic, I., & Zec, J. (2018). An Efficient Approach for Evaluating Performance of LTE Network Using Android Application in the Smart-phones An Efficient Approach for Evaluating Performance of LTE Network Using Android Application in the Smart-phones, (April). https://doi.org/10.9790/9622-0804027983

Ant, T., & Nunes, M. (2010). O Modelo Relacional, 1–8.

Burbeck, S. (1992). Applications Programming in Smalltalk-80 (TM): How to use Model-View-Controller (MVC). *Smalltalk-80 V2*, *80*(Mvc), 1–11. Retrieved from http://www.dgp.toronto.edu/~dwigdor/teaching/csc2524/2012_F/papers/mvc.pdf

Castillo, C. (2014). JavaFX Scene Builder Using JavaFX Scene Builder with Java IDEs, (April).

Communications, I. N. P. (1997). In personal communications. *Communications*, (October), 132–140.

Do, T. Van, Do, N. H., & Chakka, R. (2014). A Performance Model for the HSDPA User Equipment and its Validation, (May).

Engineering, C. (2015). HEIKKI EUROPAEUS DEVELOPING A DIMENSIONING MODEL FOR NETACT, (January).

Ericson, M., Wanstedt, S., & Pettersson, J. (2006). Effects of simultaneous circuit and packet switched voice traffic on total capacity. *2006 Ieee 63rd Vehicular Technology Conference, Vols 1-6*, (September 2014), 538–542. https://doi.org/10.1109/VETECS.2006.1682882

Fernando, D., & Pepinosa, R. (2013). Long Term Evolution), (July). https://doi.org/10.1007/978-3-319-23823-4

G.G. Liversidge, K.C. Cundy, J.F. Bishop, D. A. C. (1980). United States Patent (19) 54, *96*(19), 62–66. https://doi.org/US005485919A

Gill, D., Cosmas, J. P., & Pearmain, A. (2000). Mobile audio-visual terminal: system design and subjective testing in DECT and UMTS networks. *IEEE Transactions on Vehicular Technology*, *49*(4), 1378–1391. https://doi.org/10.1109/25.875264

Gsm/umts/lte. (2017).

Holma, H., Kristensson, M., Salonen, J., & Toskala, A. (2008). *UMTS Services*. *WCDMA for UMTS: HSPA Evolution and LTE: Fourth Edition*. https://doi.org/10.1002/9780470512531.ch2

Holma, H., Toskala, A., & Wiley InterScience (Online service). (2009). *LTE for UMTS : OFDMA and SC-FDMA based radio access*. Wiley. Retrieved from https://books.google.pt/books?id=uhr3KwSww2kC&pg=PA252&lpg=PA252&dq=hs-dsch+throughput&source=bl&ots=qgBDCYa1cE&sig=wvppLKZCcZ9q7h57g2Ckn8u1LUo&hl=pt-PT&sa=X&ved=0ahUKEwiz49f7p67YAhWPCuwKHchNCeIQ6AEIQTAD#v=onepage&q=hs-dsch throughput&f=false

Hu, H., Zhang, J., Zheng, X., Yang, Y., & Wu, P. (2010). Self-configuration and self-optimization for LTE networks. *IEEE Communications Magazine*, *48*(2), 94–100. https://doi.org/10.1109/MCOM.2010.5402670

In, a L., Roadband, I. B., El, S., Abdelali, K., Bouchti, E. L., Hanini, M., & Haqiq, A. (2012). P Erformance a Nalysis for B Andwidth. *International Journal of Wireless & Mobile Networks*, *4*(1), 139.

INTERNATIONAL TELECOMMUNICATION UNION. (2008). Telecom Network Planning for evolving Network Architectures Reference Manual part 2, (January), 1–165.

Jakobson, G., & Weissman, M. (1993). Alarm correlation. *IEEE Network*, *7*(6), 52–59. https://doi.org/10.1109/65.244794

Java, C., & Concepts, D. (2015). Eclipse Integrated Development Environment. *Simply Easy Learning*, *I*, 1–81.

Jayasinghe, G., Fahmy, F., Gajaweera, N., & Dias, D. (2006). A GSM alarm device for disaster early warning. *1st International Conference on Industrial and Information Systems, ICIIS 2006*, (January 2016), 383–387. https://doi.org/10.1109/ICIIS.2006.365757

Kadioğlu, R., Dalveren, Y., & Ali, K. (2015). Quality of service assessment: a case study on performance benchmarking of cellular network operators in Turkey. *Online.Journals.Tubitak.Gov.Tr*, (March 2018), 548–559. https://doi.org/10.3906/elk-1302-191

Klein, K. (2005). (12) United States Patent, *2*(12).

Kumar, C. S. (2015). NPO Performance Analysis :, (July).

Laiho, J., Wacker, A., & Novosad, T. (2005). *Radio Network Planning and Optimisation for UMTS, 2nd Edition*.

Larsson, N. (2015). Visualizing the status of telecommunication networks with dashboards, (June), 0–29.

Luis Delgado, J. D., & Santiago, J. M. R. (2013). Key Performance Indicators for QOS Assessment in Tetra Networks. *International Journal of Mobile Network Communications & Telematics*, *3*(6), 1–18. https://doi.org/10.5121/ijmnct.2013.3601

Mallikharjuna, N., M, M., & -, P. S. (2012). An Intelligent Location Management approaches in GSM Mobile Network. *International Journal of Advanced Research in Artificial Intelligence*, *1*(1), 30–37. https://doi.org/10.14569/IJARAI.2012.010106

Manual, M. R. (2013). MySQL 5 . 0 Reference Manual. *MySQL 5.0 Reference Manual*, *1*, 1692. Retrieved from dev.mysql.com

Meyer, M., & Allee, E. (n.d.). TCP performance over GPRS.pdf.

Min, Y., Shin, S., Sun, H., Kim, H. S., Bang, J. S., Cho, G. H., … Data, P. (2017). (12) United States Patent, *2*(12). https://doi.org/10.1038/incomms1464

Musa, S. A. (2017). Performance Appraisal of Mobile Telecommunication Network in Dutse , Jigawa State, (September).

NSN. (2013). Single RAN Advanced Evolution : The future just got simpler. *Nokia*,

(June).

Ochang, P. A., & Irving, P. J. (2016). Evolutionary Analysis of GSM , UMTS and LTE Mobile Network Architectures, *54*, 27–39.

Ontents, T. A. O. F. C. (2015). Q Uality a Ssurance a Nd a Rticulation, *7*(5), 65–76.

Perälä, P. H. J., Barbuzzi, A., Boggia, G., & Pentikousis, K. (2009). Theory and practice of RRC state transitions in UMTS networks. *2009 IEEE Globecom Workshops, Gc Workshops 2009*, (July), 3–8. https://doi.org/10.1109/GLOCOMW.2009.5360763

Pinheiro, R. F., Aguiar, A. B. De, & Pinheiro, P. R. (2010). Novel Algorithms and Techniques in Telecommunications and Networking, (June 2014). https://doi.org/10.1007/978-90-481-3662-9

Pollini, G. P. (1996). Trends in Handover design. *IEEE Communications Magazine*, *34*(3), 82–90. https://doi.org/10.1109/35.486807

Saravanant, N., Sreenivasulu, N., Jayaram, D., & Chockalingam, A. (2007). Design and performance evaluation of an inter-system handover algorithm in UMTS/GSM networks. *IEEE Region 10 Annual International Conference, Proceedings/TENCON*, *2007*(June). https://doi.org/10.1109/TENCON.2005.300980

Sheriff, R. E. (2011). Electronics and Telecommunications Research Seminar Series. *1oth Workshop Proceedings*, (April).

Soloveichik, G. L. (2011). Battery Technologies for Large-Scale Stationary Energy Storage. *Annual Review of Chemical and Biomolecular Engineering*, *2*(1), 503–527. https://doi.org/10.1146/annurev-chembioeng-061010-114116

Speed, H., Access, R., & Communications, M. (n.d.). *HSDPA / HSUPA for UMTS*.

Started, G. (n.d.). About the Tutorial. *Time*, 17–26. https://doi.org/10.1017/CBO9781107415324.004

Tiwana, M., Altman, Z., & Sayrac, B. (2010). Enhancing RRM optimization using a priori knowledge for automated troubleshooting. *Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt), 2010 Proceedings of the 8th International Symposium On*, (July 2010), 564–572. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5520337

Using XAMPP for Local WordPress Theme Development. (2015). Retrieved from http://sixrevisions.com/tutorials/web-development-tutorials/using-xampp-for-local-wordpress-theme-development/

Xiao-Fang, Z., Hua-Zhu, L., Yi, L., Shi-Gang, Z., & Sim, C. Y. D. (2018). A Low VSWR and High Efficiency Waveguide Feed Antenna Array. *Wireless Communications and Mobile Computing*, *2018*. https://doi.org/10.1155/2018/7867091

Yuan, G., Zhang, X., Wang, W., & Yang, Y. (2010). Carrier aggregation for LTE-advanced mobile communication systems. *IEEE Communications Magazine*, *48*(2), 88–93. https://doi.org/10.1109/MCOM.2010.5402669

Appendix A

```
MSCi      MSSRH05                    2018-09-20  12:21:37

SEARCH CALL PATH

 LEG TYPE     : ORIGINAL
 LEG CALL ID  : 59C7H-00000B3BH-4004H-7012H-187BH-1CH-7012H-2295H-7AH
 ORIG CALL ID :
 CALL START   : 2018-09-20 12:21:28  TARGET     : MSC   /SCALLF
 SIGN COMP    : 2018-09-20 12:21:30  CALL TYPE  : OUTGOING
 ANSWER       : 2018-09-20 12:21:36  CALL PHASE : CONVERSATION
 CHAR END     : ....-..-.. ..:..:..  STAT STATE : AB SEIZED
 LAST MESSAGE : 2018-09-20 12:21:36  D5C8
 CLEAR CODE   :
 UNIT ID      : GISU-023


 CALLING NUMBER        : I  5592984430221
 CALLED NUMBER         : I  550320999092991061338
 OUTPULSED NUMBER      : S  092991061338
 CONNECTED NUMBER      :
 FORWARDED TO          :
 ROAMING NUMBER        :
 ADDRESS NUMBER        : U  991061338

OBJECT                   SUBSCRIBER A                SUBSCRIBER B
 TRACING REF/TYPE      :      /                           /
 IMSI                  : 724059205660410
 IMEI                  :
 RADIO SYSTEM          : GSM
 CGR/PCM-TSL/STATE     :      /     -  /R               01501/02670-20/R
 BICC CIRCUIT
    NET                :
    SPC                :
    CIC                :
 MGW                   : VDMSRTK05MSSRH05             VDMSRTK05MSSRH05
 BNC CHAR              : IPV4                         TDM
 TDMTERMID             :      -                       03310-20
 TERMID                : 370449C0
 CNTL TYPE/INDEX       : GISU/00023                   GISU/00022

 SPTD CODEC LIST       : UMTS AMR   /UMTS AMR 2
 MCC/MNC               : 724 /05                         /
```

Figure 59 - The Test call in MSS source from anonymous

The Figure 59 shows the test call in MSS where the call type is ongoing, the call phase is in conversation status, radiating in BSC ID = 00100, LAC = 00992 and the CI = 04101, and also the Channel Rate is radiate in HFR (Half Rate) or FR (Full Rate).

Appendix B

```
MCC/MNC                 : 724 /05                          /
BSC/LAC/CI              : 00100/00992/04101                 /     /
RNC                     :
NAME/INTRA CI           : RTPCSD2136 /3422                        /
LOCATION NUMBER         :
USED CODEC              : HR AMR                       G711 A
MODES LIST              : 4.75
                          5.90
                          7.40
CHANNEL RATE            : FRP /HFR1/FR                    /    /
SPEECH VERSION          : FR3
LSA                     :
USED CHANNEL CODINGS    :
PRIOR/CATEG             :  1/ORDINARY                    /UNKNOWN
MS CLASSMARK            : 0                             -
MS UMTS CAPABILITY      :
IN CATEGORY KEY         :

CAMEL CALL ADDRESS      : 550050910012
CAMEL REF NUMBER        : 40047012187B1C
CTM TT CAPABLE          : NO
TEST CALL CATEGORY      :
SUPP SERVICE            : CAMEL

BACK/FORW               :                                 /
HO LINK                 :
ROAM LINK               :
INTERCONNECTING TDM     :      -                             -
ANCHOR IC TDM           :      -


ECHO CANCELLING PARAMETERS
RECEIVED IEC / OEC    : INCLUDED / INCLUDED
SENT IEC / OEC        : INCLUDED / INCLUDED
IEC STATE / OEC STATE : ENABLED /

ICC-PID  7012H/0134H/1C1BH/BEH
SSI-PID       /     /     /
SSO-PID  700EH/01CAH/0D43H/7DH
AIFI-PID 7012H/0132H/0697H/39H
AIFO-PID      /     /     /
OCC-PID  7012H/0161H/10E3H/82H
CFO-PID       /     /     /
```

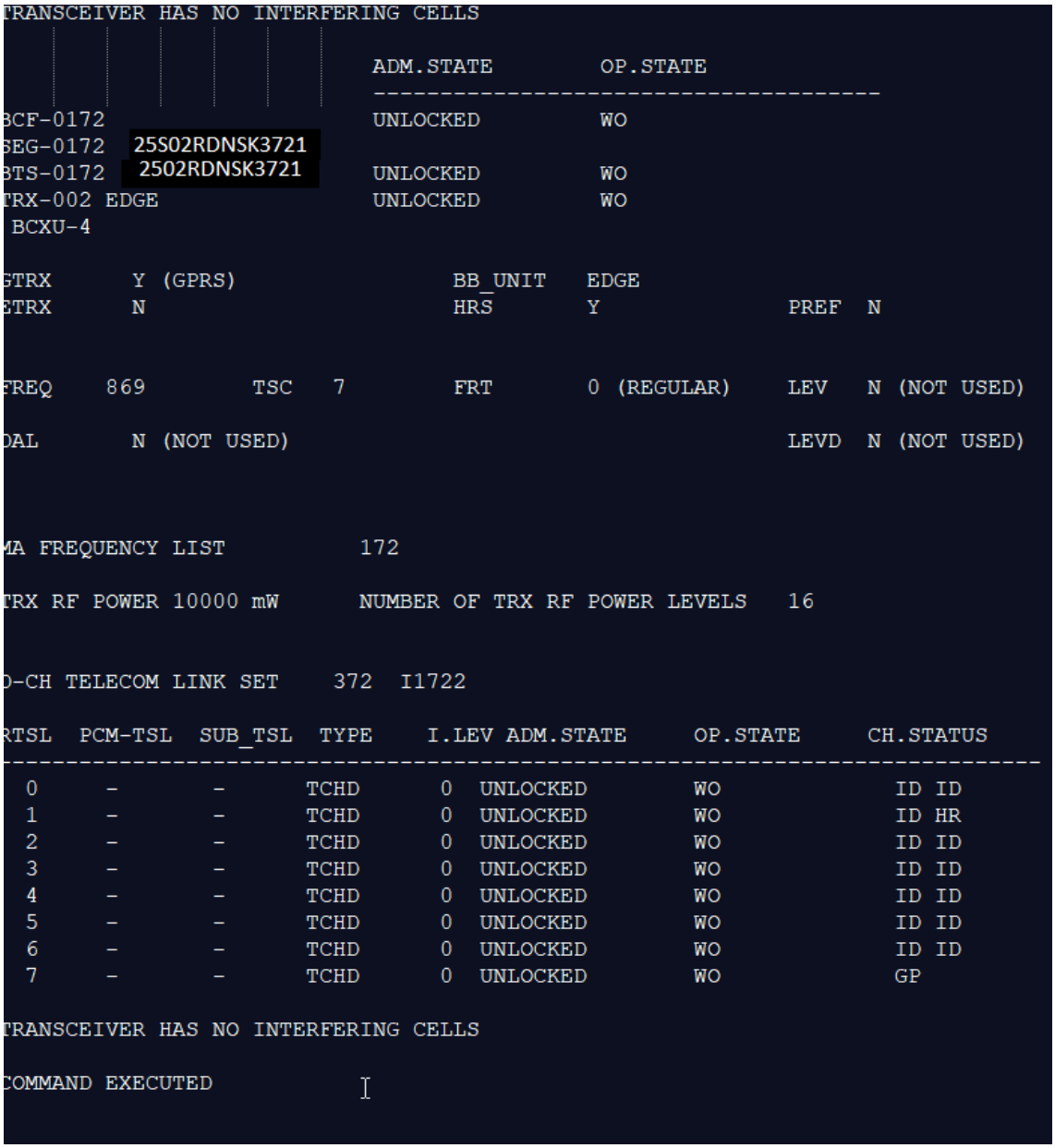


Figure 60 - The Test Call in BSC source from anonymous

The Figure 60 Shows the teste call in BSC where the Channel status is HR in other word means the call is pass in this channel, OP. state its WO.

Appendix C

Figure 61 - Single RAN Version 17 source from anonymous

The Figure 61 Shows the Single Ran version 17 where it interface have many modifications shows the fan controller and fan group, the system module, cabinet 1 and 2 cable connection whit cells, BTS Mediator and so on