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STUDY ON QUALITY OF SERVICE IN 4G AND 5G NETWORKS

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STUDY QUALITY SERVICE IN 4G AND 5G NETWORKS

The study of Quality of Service (QoS) is becoming increasingly important since QoS is considered equally important as network security. It is vital to offer sufficient QoS in services considered critical such as communications networks in emergencies, remote control of machinery, or in the future, to be able to perform remote operations thanks to technology such as 5G.

This thesis presents the study of QoS in mobile communication networks. The main objectives were to describe the most relevant theoretical aspects in 4G and 5G networks, the changes in the field of new developments, G-NetTrack Pro and Qosium, the two tools to perform QoS measurements in mobile networks and finally, to perform QoS measurements in a research environment. It was expected that from the results obtained; conclusions will be drawn about the tools used for future research projects in mobile communications.

The methodology consisted of measuring the performance of a 4G network by measuring the QoS delivered in two services with very different requirements. Measuring QoS in Voice Over Internet Protocol [VoIP] calls and measuring QoS in a video-streaming.

With the results obtained, it has been possible to observe the excellent performance of the network under various indoor and outdoor conditions, and it has been possible to apply the theoretical knowledge previously studied. Finally, the advantages and disadvantages of the tools used have been identified.

It is expected that this thesis will be useful for future projects of the research group 5GTNT measuring QoS with the described tools. In addition, the results and conclusions can also be used by third parties since the results and conclusions can be useful for research and industry environments.

KEYWORDS:

VoIP, video streaming, cellular networks, wireless communications.

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LIST OF ABBREVIATIONS

3G	Third Generation of Cellular Network Technology
3GPP	The 3rd Generation Partnership Project
4G	Fourth Generation of Cellular Network Technology
5G	Fifth Generation of Cellular Network Technology
5GTNT	5G Test Network Turku
AMF	Access and Mobility Management
B2BUA	Back to Back User Agent
CS	Circuit Switched Based (CS)
D2D	Device-To-Device
DiffServ	Differentiated Services
DL	Downlink
DSCP	Differentiated Services Code Point
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
eMBB	Enhanced Mobile Broadband
eNodeB	Evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
FDMA	Frequency Division Multiple Access
GBR	Guaranteed bitrate
GPRS	General Packet Radio Service
GTP	General Packet Radio Service Tunneling Protocol
GTP-C	GTP-Control Plane
GTP-U	GTP-User Plane
GW	Gateway
HDR	High-Dynamic-range imaging
HSS	Home subscriber server
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers

IntServ	Integrated Services
IoT	Internet of Things
IP	Internet Protocol
IP-CAN	IP Connectivity Access Network
IPTV	Internet Protocol television
IPTV	IP Television
ISDN	Integrated Services Digital Network
ITU	International Telecommunication Union
LTE	Long Term Evolution
MBR	Maximum bitrate
MCC	Mobile Country Code
MCPTT	Mission-critical push-to-talk
MIMO	Multiple Input Multiple Output
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
mMTC	Massive Machine Type Communications
MNC	Mobile Network Code
MOS	Mean Opinion Score
MOS	Mean Opinion Score
NR	New Radio
NR	New Radio
OFDMA	Orthogonal Frequency Multiple Access Division
OTT	Over The Top
P2P	Peer-To-Peer
PCF	Policy Control Function
PCRF	Policy and charging rules function
PDN-GW	Packet Data Network Gateway
PER	Packet error Rate
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation

QCI	Quality of Service class identifer
QoE	Quality of Experience
QoS	Quality of Service
RSVP	Resource Reservation Protocol
RTP	Real-time Transport Protocol
S-GW	Serving Gateway
SIP	Session Initiation Protocol
SMF	Session Management Function
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UDM	Unified Data Management
UDP	User Datagram Protocol
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UPF	User Plane Function
URLLC	Ultra-Reliable Low-Latency Communications
V2X	Vechicle-To-X
VoIP	Voice over Internet Protocol
VoLTE	Voice over LTE
WCDMA	Wideband Code Division Multiple Access
www	World Wide Web

1 INTRODUCTION

The term Quality of Service [QoS] was introduced in 1994 in the International Telecommunication Union [ITU] in the E800 recommendation for Qos in telephony (1). Since then, both the technologies and the development of QoS have advanced to what we know today as the broadband access internet. These advances have enabled the creation of new services and introduced new challenges to meet their requirements.

The development of mobile communications, especially the fourth and fifth-generation [4G and 5G] and the emergence of new technological devices, have led to a massive change in the volume of data across networks. For example, we have switched from using the internet to sending an email from the office to watch live video in 4k quality anywhere thanks to wireless communications.

Due to these facts, the importance of QoS has not stopped growing over the years, as the need to offer different types of content with their requirements in terms of quality and security has increased. Among the greatest challenges of offering QoS from point to point is the scenario of offering QoS in mobile communications where the user is on the move along with different locations that make the signal varies significantly, making it challenging to offer quality content increase or decrease.

Multiple QoS studies have been published by different companies and institutions such as Cisco, Microsoft, or the Institute of Electrical and Electronics Engineers [IEEE]. Most of them focus on computing, policing, performance, architecture, and the optimization of mechanisms associated with QoS. Some publications associated with the study of QoS in mobile communications can be found in (2-4).

The purpose of this thesis is the study of QoS in mobile communications as 4G and 5G, studying the major differences that can be found between 4G and 5G, as well as the advantages and disadvantages of each of them. The analysis of QoS measurements taken in the laboratory will also be carried out using passive QoS measurement tools. These tools are G-NetTrack Pro and Qosium.

This thesis's main scope is to analyze the advantages and disadvantages of the tools used to measure QoS since its importance is vital when developing a new wireless communications technology. Thanks to these tools, it is possible to optimize the performance of the network in its development phase, but also to optimize its implementation in industrial applications. For this reason, as appendices have been included with guidelines to carry out measurements with G-NetTrack Pro and Qosium that can be very useful in future projects carried out by the 5GTNT research group.

The thesis is structured as follows: Chapter 1 describes the objectives of the thesis and the overview of the thesis structure. Chapter 2 describes the technical and theoretical aspects of Qos over the years. Chapter 3 describes the QoS in mobile communications of the last generations as 4G and 5G, besides studying the main characteristics of these two technologies. The last chapter describes the results obtained performing QoS measurements in a 4G network in the Radiolab of the 5GTNT research group (5).

2 QUALITY OF SERVICE

2.1 Definition

QoS has its origin in telephony. It was designed for the end-user to be a person listening to a phone conversation with decent quality. The low packet loss ratio is acceptable for voice, and the end-to-end delay for voice should less than 400 ms.

However, technology has advanced by leaps and bounds, and today many applications do not need real-time delivery, and the sender or the end-to-end user may not be a person.

Therefore, it is necessary to take into account that the definition of QoS is very general since QoS is present in multiple different applications.

ITU defines "Quality of service [QoS] is totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service"(6) .

In the telecommunications field , QoS is always an end-to-end characteristic.

2.2 Introduction to QoS background and actuality

QoS was conceived to offer a guarantee of service in the Telecom world [telephony], but at the same time in the 80-90s, the Internet world was starting to take its first steps. These two worlds were conceived in different ways, but over the years, they have evolved in parallel to the point where it seems that they will merge and give way to a single environment, the Internet, based on IP Traffic. A key factor has been the development of key technologies such as fiber optics, broadband Internet access, and finally, the development of wireless communications that allow millions of users to enjoy high bandwidth connectivity and speed virtually anywhere.

Internet protocols try to offer the service with the highest possible performance, i.e., the highest possible bitrate and the lowest latency and delay, as long as there is no congestion on the network. Network congestion is inevitable because network traffic increases exponentially, while infrastructure improvements are slow and costly. Thus, it is essential to implement end-to-end Quality of Service in those services where a drop in the quality of service can not be afforded, such as video calls, Voice over Internet Protocol [VoIP], critical infrastructure communications, or other applications focused on the world of entertainment as video-streaming on demand.

The Internet infrastructure tries to offer the best possible service within the different limitations that may exist, temporary co-management, breakdowns, location when using wireless communications. QoS is considered a fundamental network feature since, without it, it is impossible to guarantee the service in the critical infrastructures or give good quality of experience to the final user. Overall, QoS is considered as essential as security.

The first issue is that the traditional Telecom world has mandatory QoS mechanisms, whereas the Internet World was not conceived with QoS mechanisms. Hence, the ITU decided in 2003 to start the standardization of the end-to-end QoS support in all-IP networks, which is essential for real-time services, such a VoIP and Internet Protocol television [IPTV]. These services have rigorous requirements regarding QoS (guaranteed bitrates, delay, jitter, losses)(2).

2.3 The importance of QoS in Mobile broadband Networks

Telecommunication networks are interconnected locally, regionally, and globally to connect two or more points on the earth and transfer data. The quality of telecommunication services is influenced from end to end.

Mobile communications are having a significant impact on the transition from the ICT environment to an all-IP-based environment, as evidenced by the data provided by (7). It is interesting to notice that mobile communications are reaching more people much faster than fixed communications, as shown in Figure 1.

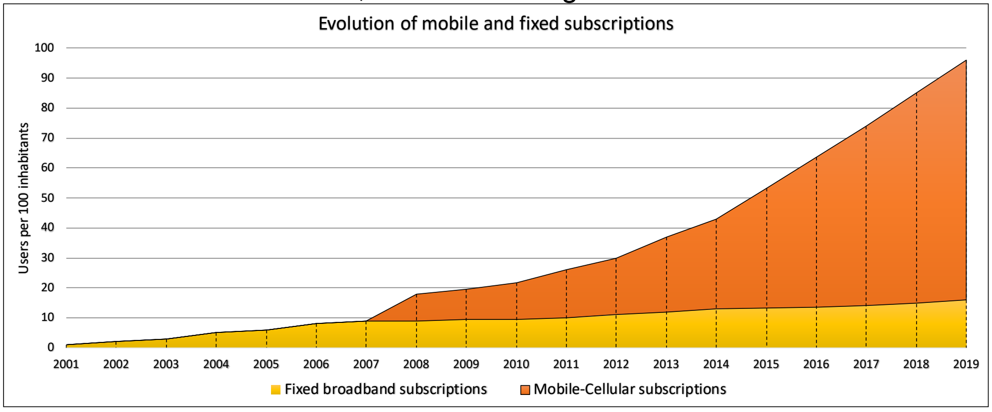


Figure 1. Evolution of mobile and fixed subscriptions (7).

A significant change can be seen between the 2001 and 2007?, where about 1% of the population had a mobile subscription while 10% had a fixed subscription.

The situation is almost the opposite today, as the number of mobile subscriptions is much higher than fixed subscriptions.

Mobile broadband

The cellular broadband technologies appeared in the 2000s with the third generation of mobile networks [3G] and later followed with the fourth generation [4G] and now with the fifth-generation [5G]. Figure 2 describes the availability of each technology according to the world population. The figure shows that 2G remains the most widespread mobile technology in the world.

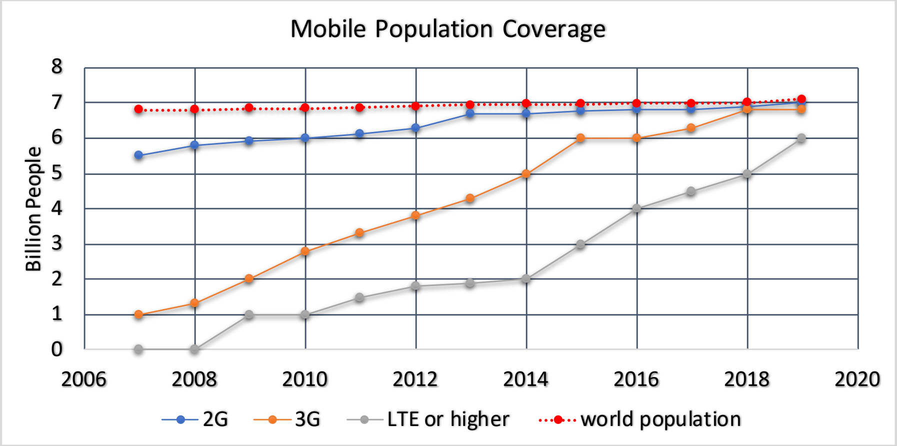


Figure 2. Mobile Population Coverage by cellular technology (7) .

Mobile communications have improved, among other aspects, in performance and in coverage at a global level, making it possible that today we have within a reach ultra-fast access to the Internet.

As a result, traffic worldwide has increased, and the user's expectation has changed, i.e., what a user expects from the QoS of service will not be the same in 10 years, as QoS requirements and the expectation of users change over time.

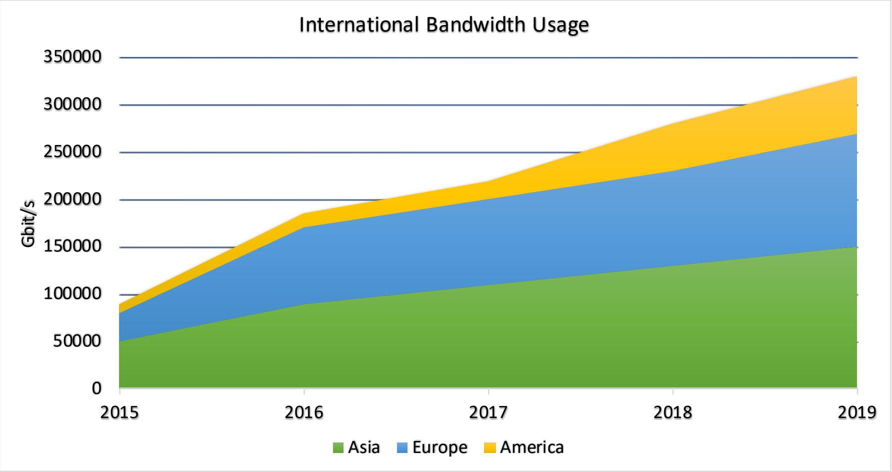


Figure 3. International Bandwidth Usage in Gbit/s (7).

In Figure 3, we can see a significant increase in broadband Internet use in terms of Gbit/s; a determining factor has been the popularization of video-on-demand services along with the possibility of enjoying these anywhere with technologies such as LTE advanced or 5G. In the next section, we will study the parameters and techniques that can provide a QoS suitable for each situation and application.

2.4 Definitions of QoS, QoE and Network Performance.

It is important to mention and clarify the differences and relationships between QoS, Quality of Experience [QoE], and Network Performance [NP] since sometimes they can be confused with each other. Figure 4 helps to locate where every term is present.

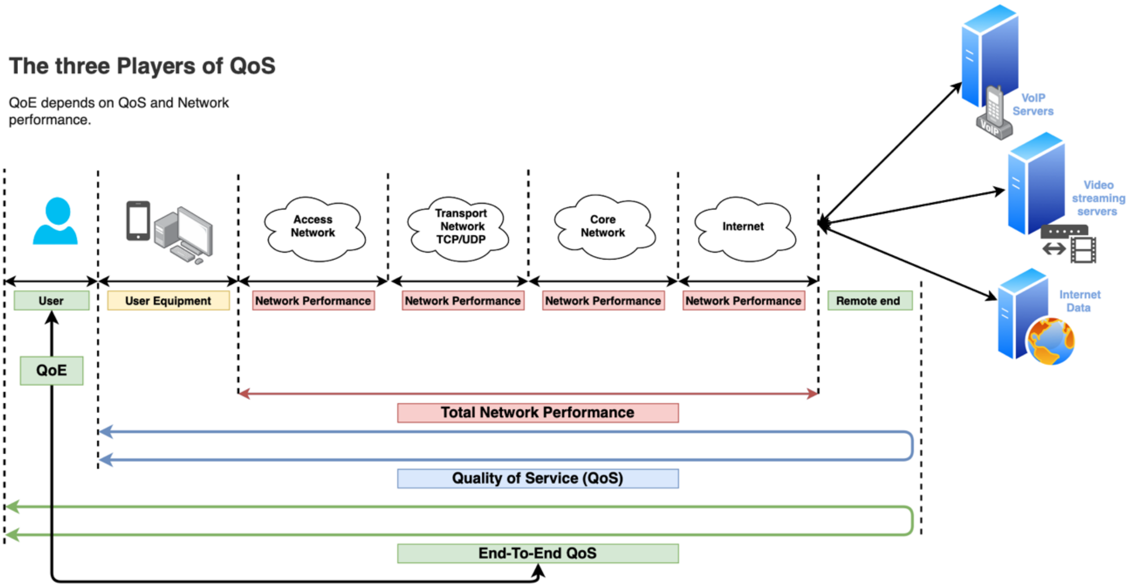


Figure 4. QoS, QoE, and Network Performance parameters depicted in network infrastructure.

NP, QoE, and QoS are related to each other. QoE depends on QoS and NP, i.e., if there is congestion in the network and consequently NP is lower, the result will be poor quality experienced by the end-user. As shown in Figure 4 and as defined in (6), NP is the technical part of QoS and contributes to QoS that the user experiences, i.e., delay, jitter, and bitrate.

Another aspect that we can see in Figure 4 is that QoS is always end-to-end, being user-to-content, user-to-user, or machine-to-machine. This means that QoS is affected by the NP of each component from beginning to end, that is, Access network, Core network, Transport Network, Servers or even the user's terminal, while QoE has a broader scope since it is affected by end-to-end QoS but also by the user's expectations.

QoE criteria

The evaluation of QoE is performed using a subjective test called Mean Opinion Score [MOS], whereas the evaluation of QoS is performed using objective measures.

The MOS is mainly used in services such as IPTV or video-streaming since this is a subjective measure given by the opinion of the user who is consuming the service or content. This measure is given by a single number between 1 and 5, as shown in Table 1.

Table 1. MOS in terms of QoE (2).

Mean Opinion Score (MOS)	Quality classification
5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

2.5 Internet Traffic Characterization for QoS

There are different applications/services on the Internet with different requirements and, in some cases, with certain QoS guarantees. All Internet traffic can be grouped into three main categories: audio, video, and data. Each specific type of traffic has its own characteristics that influence the performance of the network and QoS solutions.
If the QoS guarantees are weak in audio, high delay during VoIP call, or low bitrate in a video-streaming, the user QoE will be affected.

Audio Traffic related to QoS

Audio is a type of conversational traffic, so it has similar requirements between conversations from A to B and vice versa. Among the requirements is a constant bitrate for both receiving and sending. This type of traffic is especially sensitive to delay and jitter. It is recommended that the delay should be less than 150 ms, and higher than 400 ms is not acceptable as users would start talking and disturbing each other.(8)
When we talk about the IP environments, the delays are greater than 150 ms due to the buffering in every node.
All the nodes in the network have different buffer levels with different queue lengths that introduce different delays in the IP packets.
In general, audio has a better tolerance to the errors than video because of human hearing can interpret broken words caused by IP packet loss.
Typically voice traffic is a continuous two-way stream with strict delays, usually carried by RTP-UDP-IP protocol stack. Voice is considered a type of real-time traffic (2).
There are two types of voice services:

1. Voice over LTE [VoLTE]: where the telecom operators provide this voice service and therefore has certain guarantees in terms of QoS.
2. Over the top voice services [OTT voice services] commonly known as voice calls through Skype, Facetime, WhatsApp over the public Internet following a best-effort protocol, although in the queues of the nodes is given priority to voice over IP packets.

Video Traffic related to QoS

Video represents about 80% of Internet traffic, and the trend is growing (9). To save bandwidth, almost all video distributed over the Internet today is compressed. The most common video compression standard is MPEG-2 and MPEG-4, more information at (10,11) Regardless of the type of video, whether it is a streaming video or a video call, the video is based on RTP-UDP-IP or HTTP-TCP-IP, the latter with longer delays due to the retransmission of lost TCP segments. In services such as IPTV, proprietary protocols such as IPTV protocol are starting to be used to offer live TV over the Internet.
Video is more tolerant of delays than audio but less tolerant of losses in(8)defines the minimum requirements to offer an adequate QoS.

a. There are two types of two video.
b. The first type is Video calls, a type of bidirectional video with requirements very similar to the voice calls 150 ms delay in one direction, and a maximum of 400 ms delay the tolerance to losses is 1% while the audio can be 3%.

c. The second type is one-way video with <10 s delay tolerance and 1% loss tolerance.

2.6 DiffServ and IntServ Traffic management Protocols

2.6.1 Integrated Services [IntServ]

Integrated Services is a structure that is intended to provide QoS guarantees in IP environments for individual sessions. It makes use of the Resource Reservation Protocol [RSVP] (12).
RSVP is usually implemented in the routers. These routers contain databases with records of the resources available at each moment. The IntServ domain extends from host to guest, see Figure 5 each router in the route between host and guest must reserve resources to ensure QoS when the RSVP call occurs. These resources are usually bandwidth.

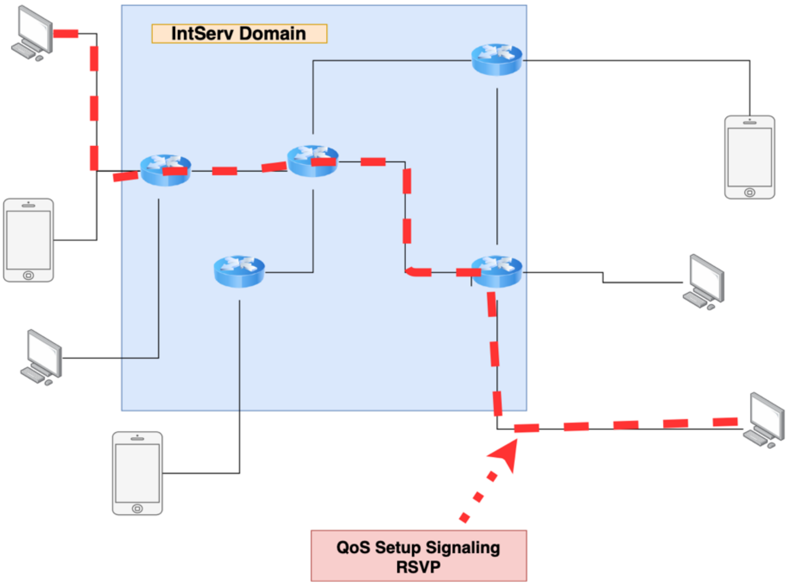


Figure 5. QoS setup signaling RSVP for IntServ

2.6.2 Differentiated Services

Differentiated Services, unlike IntServ, divide Internet traffic into different classes, assigning each class different priorities and QoS. Offering Scalability, Flexibility, simpler RSVP signaling, and traffic conditioning.
Figure Figure 6 shows the differentiated Serivices marking the packets with the DSCP codes that are described in Figure Figure 7. More technical information can be found in (13)

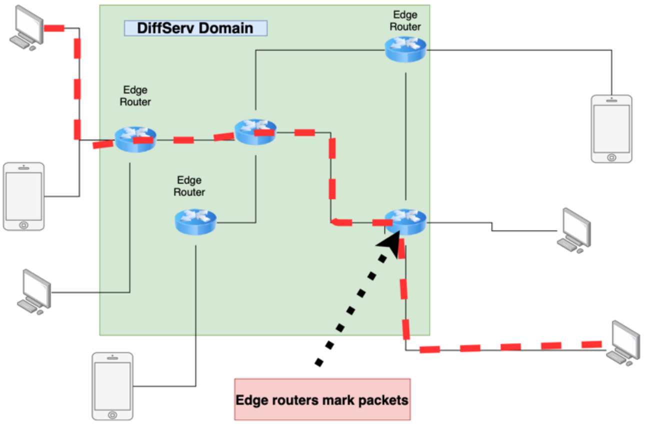
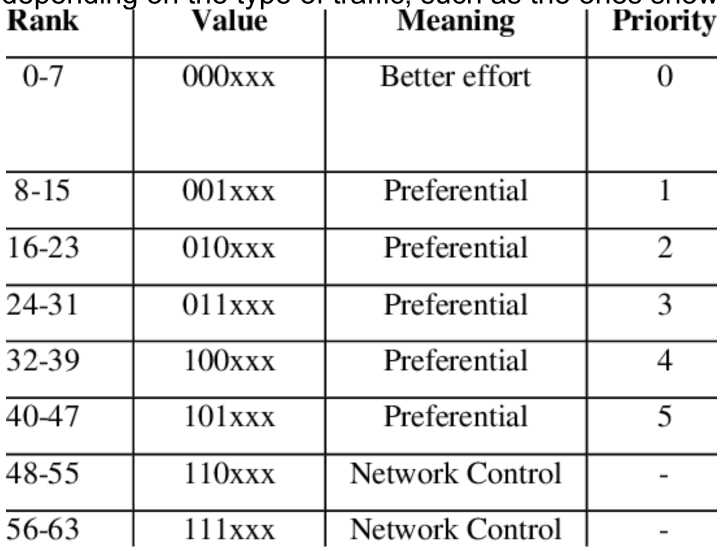


Figure 6. DiffServ architecture

There are significant differences to be mentioned:

- DiffServ has better scalability than IntServ because maintaining states on the routers when the environment is a high-speed network is challenging to achieve.
- Signaling is much simpler with DiffServ than RSVP [IntServ]. From simple functions in the Core network to more complex identification, shaping, and dropping functions in the edge routers.

In general, Differentiated Services Code Point [DSCP] codes are used where priorities are established depending on the type of traffic, such as the ones shown below:



Rank	Value	Meaning	Priority
0-7	000xxx	Better effort	0
8-15	001xxx	Preferential	1
16-23	010xxx	Preferential	2
24-31	011xxx	Preferential	3
32-39	100xxx	Preferential	4
40-47	101xxx	Preferential	5
48-55	110xxx	Network Control	-
56-63	111xxx	Network Control	-

Figure 7. DSCP Table codes (14).

In 0 section a real example of using this codes is depicted.

2.7 Conclusions

In this chapter, we have presented the beginnings of QoS in telephony and later its introduction to the Internet. The use of QoS on the Internet is fundamental, although, by default, the Internet does not provide a QoS mechanism since it is based on best-effort. QoS becomes vital when the amount of traffic is reaching the maximum capacity of the infrastructure, and this can happen at any point in the network since QoS is considered to be end to end. Therefore the use of mechanisms that help to decongest the network is necessary for each of the network nodes without distinguishing between optical fiber technology, coaxial cable, or cellular networks.

Mechanisms such as DiffServ and IntServ that were standardized in the late 1990s are crucial to ensuring QoS when there is congestion. They have not stopped evolving to adapt to the increase in network traffic and the arrival of new technologies as they will have to do in the future to offer QoS guarantees to key technologies such as the IoT or emerging cloud computing. The aim is still to offer QoS on the Internet as a whole and not to specific applications such as IPTV, VoLTE, or key users such as industry and business.

In the next chapter, we will explain the most important wireless technologies nowadays and the most relevant technical aspects.

3 CELLULAR COMMUNICATIONS TECHNOLOGIES

Wireless communications technologies have kept evolving since 1981, with the introduction of Nordic Mobile Telephony, also known as the first generation [1G]. It was the first widely deployed mobile communications system.

However, it was not until July 1, 1991, when the first digital call Global System for Mobile Communications [GSM] was made between Helsinki and Tampere (Finland) this historic event marked the beginning of a race to develop wireless communications as we know them today, with the deployment of ultra-fast wireless communications with the fifth-generation [5G] of mobile communications.

The following is a chronological definition of each of the five mobile generations and what improvements they introduced.

- **1G** refers to analog mobile communication systems in the 1980s. It used frequency division multiple access [FDMA) technology].
- **2G** first introduced mobile digital systems in the 1990s based on Time Division Multiple Access [TDMA] and FDMA. This second-generation was based on Circuit-Switched-based [CS]. Its most important applications were in mobile voice and SMS. Afterward, 2.5G was released with packet-switched [PS] that is GPRS from 3GPP.
- **3G** was perhaps the first technology that allowed us to see how the future of mobile communications was going to be since it showed evidence of the potential of having broadband access on a mobile phone in the pocket with the possibility of consulting the email or loading web pages. It used various technologies such as Wideband Code Division Multiple Access [WCDMA], in addition to TDMA and FDMA.
- **4G** launched in 2010 was the first generation, which is all IP by default. It was focused on IP services instead of telephony services such as voice calls or messages. Based on Orthogonal frequency multiple access division [OFDMA] technology, combined with TDMA to support QoS.
- **5G** has started to deploy the first commercial networks. This generation is destined to change the 2020s with the revolution in many sectors such as industry, healthcare, technology, automotive, the previous generations meant the revolution in IP services, with this generation the revolution goes much further. Among its improvements, it offers a higher data speed than its predecessors, besides adding the possibility of network virtualization where a dedicated virtualized network can be used for specific services, contributing to lower latencies. For the first time in mobile network technologies, this technology is not only focused on mobile communications. Each of these network slices can be applied in autonomous cars, with edge computing, ultra-reliable communications, and ultra-low latency communications. (e.g., locating dedicated network slices next to the road autonomous cars will send the information and process it in real-time and send it back to the car thanks to URLLC and making decisions in real-time, like avoiding accidents (15).

Today the digital technologies that continue to be available are 2G, 3G, 4G, and 5G. Older technologies such as 2G and 3G are still maintained for two reasons: the first to support "legacy" devices and the second because new uses have been found for these technologies such as IoT. These technologies need low power consumption and low data transmission, which 2G and 3G can offer. Nevertheless, this is a temporary solution until new technologies focused directly on IoT are deployed, such as LTE-M or NB-IoT. So in the next years, we will see how, on the one hand, the older generations lose market share to the newer 4G and 5G their natural successors. As can be seen in Figure 8, 2025, there will be 8 billion mobile subscribers in the world.

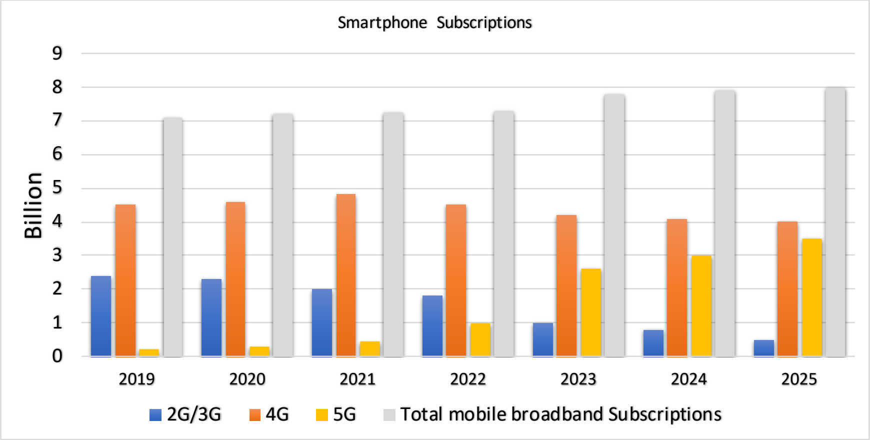


Figure 8. Mobile Subscriptions by technology (Billion) (16).

3.1 Cellular Networks architecture in details

The following section will present the most technical aspects, such as the architectures in the most recent and current 4G and 5G mobile communication networks. Since this thesis focuses on describing and contextualizing the present time of mobile communications, especially the treatment of QoS in applications that have their largest use in mobile terminals such as VoIP and video-streaming that need an excellent QoS policy for QoE to be appropriate. Next, we are going to see what structures make it possible to offer QoS in mobile terminals.

3.1.1 The 4G Network Architecture

The fourth generation of mobile networks is Long Term Evolution [LTE], which was standardized in release 8 in 2008.
3GPP is in charge of standardizing the radio access part, IP Core network segments like interfaces, gateways, and databases.
The main motivations for developing LTE are, from(17):

- Need to ensure the continuity of competitiveness of the 3G system for the future
- User demand for higher data rates and quality of service
- Packet Switch optimized system
- Continued demand for cost reduction [CAPEX and OPEX]
- Low complexity
- Avoid unnecessary fragmentation of technologies for paired and unpaired band operation.

3.1.2 4G Architecture Description

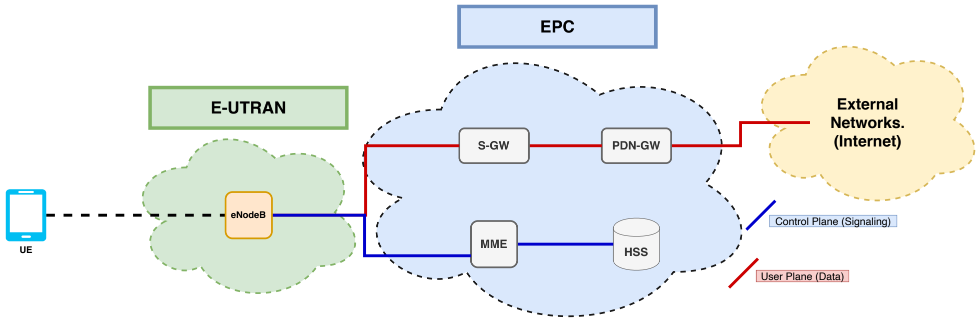


Figure 9. LTE Architecture, E-UTRAN and EPC (18).

Figure 9 Describes a fundamental architecture of the LTE architecture when a User Equipment [UE] is connected to Evolved Universal Mobile Telecommunications System [UMTS] Terrestrial Radio Access [E-UTRAN], the LTE Access Network. The Evolved NodeB [eNodeB] is the base station for LTE Radio. Besides, in this figure, the EPC is composed of four Network elements: the serving gateway [S-GW], the Mobility Management Entity [MME], and the Home Subscriber Server [HSS], the Packet Data Network Gateway [PDN GW] which connect the EPC to external networks(18).
The EPC was introduced with Release 8 (18) and Control-/User Plane Separation [CUPS] in release 14 (19). One of its most significant new features was to separate the User Plane and the Control Plane, to offer independent scalability.

HSS

Essentially HSS is a database that contains information related to the user and subscriber profile, i.e., services available to each user. It also provides support functions in mobility management, call and session setup, user authentication, and access authorization.

S-GW

This Gateway deals with user traffic [user plan], transporting IP traffic between UE [User equipment], and external Networks like the Internet. S-GW is the intermediate point between the radio interface and the core network [EPC], routing all the traffic between sides. Among its primary functions are the handling of handovers in case the UE is moving, and there is a change of eNodeB.

PDN-GW

This gateway is responsible for connecting the EPC to external networks, as well as routing IP packets. Among its most essential functions are IP address, IP prefix allocation, and QoS policy control. Since "inside" PDN-GW is Policy and charging rules function [PCRF], it aims to identify the service flow and determine policy rules for it in real-time..

MME

The Mobility Management Entity [MME] is in charge of controlling the control plane or signaling. It handles the signaling related to the mobility and security of E-UTRAN Access. Among its functions is to determine when the UE enters in idle mode and exits.

3.1.3 LTE advanced.

The International Telecommunication Union is in charge of defining the technical requirements that must be satisfied by the generations of mobile networks; for example, it was defined that LTE should reach 1Gbit/s in downlink speeds, which cannot be achieved in the release 8 in 2008. Later on, in release 11 LTE-advanced was standardized and met the requirements, besides incorporating new features such as carrier aggregation, which is the use of several carriers in the same frequency band, increasing the bit rate and the bandwidth up to a maximum of 100MHz, see Figure 10(20).

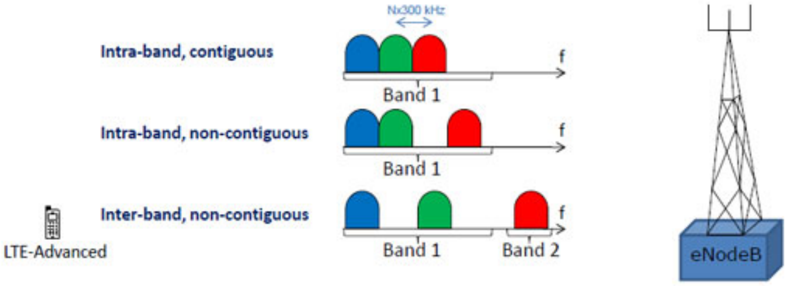


Figure 10. Carrier Aggregation; Intra-band and inter-band aggregation alternatives, from (20)

Figure 10 shows the different configurations in carrier aggregation technology. In Release 10 and 11, it is specified that LTE can use frequency carriers with different bandwidths starting from 1.4, 4.5, 10, 15, or 20 MHz with a maximum of 5 components and a maximum bandwidth of 100 MHz. It is specified that the number of carriers can be different in DL and UL being always the number of UL carriers less or equal to the number of DL carriers. It is assumed that the greater the number of carriers and bandwidth, the higher the bitrate and the better the QoS.

In LTE advanced, carrier aggregation is extended to 32 carriers x 20 MHz, allowing an overall transmission bandwidth of 640 MHz. The disadvantage is that the spectrum is limited and very expensive since it is licensed, so even if we have this possibility, it is complicated to see it implemented since the operators do not have so much spectrum available.

In releases 13 and 14, the latest before 5G, 3GPP published new specifications related to LTE advanced, defining LTE-Advanced-Pro, based entirely on LTE advanced, but with additional features for the professional sector.

New features such as LTE for V2X [vehicle-to-X] communications, Low latency LTE, or Cellular Internet of Things are the beginning of a new type of cellular communications to provide new services to users and the professional world. These technologies will continue to evolve in the fifth generation. They also represent a new challenge in implementing specific QoS on these technologies that can support critical services.

3.2 QoS in 4G

Before we start describing the more technical details such as parameters and mechanisms, it is convenient to describe the types of classes that we can find in the definition of QoS for mobile communications, especially from LTE since it is the first technology to be based entirely on IP connectivity.

Table 2 Definition of the different types of class in QoS for mobile networks, from (2)

Class	**QoS parameters**	**Examples**
Conversational	Low delay, very low delay variation. Preserved time variation between IP packets.	Real-time services over IP: VoIP, conferencing.
Streaming	Preserved time variation within a given flow. No strict requirements for low delay.	Streaming services like audio and video.
Interactive	Low round trip delay time and low bit error rate.	Non-real-time services. Interaction client-server. i.e., Web browsing, database retrieval.
Background (least priority)	Flexibility with delay and delay variation (jitter)	Email, file downloading

Table 2 describes in very general terms the four types of data traffic classes based on IP connectivity that can be carried in mobile networks, besides the QoS parameters that are most influential in providing good QoS to the user.

3GPP standardizes QoS support in mobile networks. Where "the bearers" are defined. What is a bearer in 4G/5G networks? The bearer can be defined as an enabler for data transmission between two defined points in the mobile network, including RAN and Core Network, i.e., from UE to the GW.

3GPP defines the use of protocols for tunneling to provide QoS along with the cellular network, which enables the possibility to add the same kind of traffic in a tunnel. In this way it is possible to offer QoS for each of the classes mentioned in Table 2, differentiating by class and not by flow.

The standard that defines 3GPP is General Packet Radio Service Tunneling Protocol [GTP]. We specify three types of GTP.

1. General Packet Radio Service Tunneling Protocol-Control Plane [GTP-C]. It is used for signaling traffic, bearer activation, modification, and handovers transferring the data before the handover to the new eNodeB.
2. General Packet Radio Service Protocol-User Plane [GTP-U]. It is used for carrying user data traffic between eNodes and P-GW.
3. General Packet Radio Service Protocol [GTP’] [GTP prime]. it has the same message structure as GTP-C and GTP-U, and it is used to transport the charging data towards the network operator’s billing center.

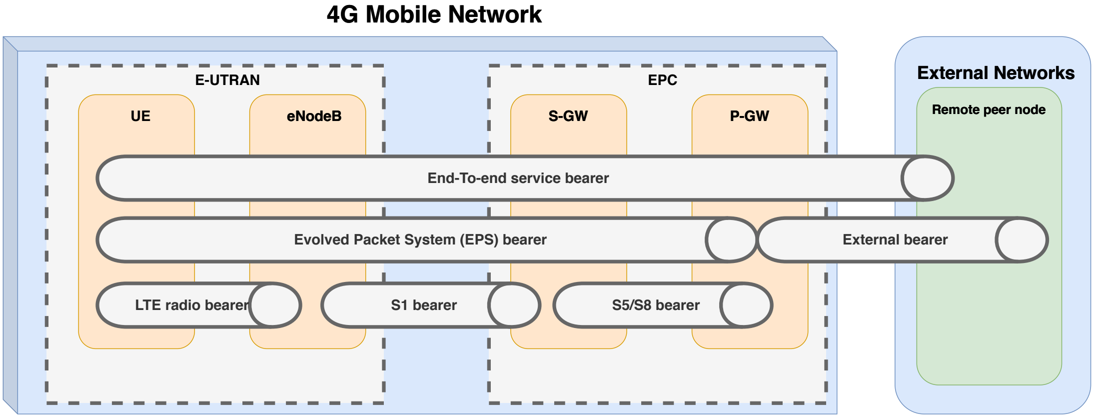


Figure 11. 4G bearers enabling end-to-end QoS support (2).

As illustrated in Figure 11, the End-to-end service bearer consists of the Evolved Packet System [EPS] bearer and an external bearer. Within the network architecture, the EPS is separated into two parts, the first is the E-UTRAN, and the second is the EPC. At least one EPS for basic IP connectivity (the default bearer) is established at each mobile terminal [UE] connected to the network. But as mentioned above, one bearer per service class can be used if they require a specific QoS.
The EPS is constituted by three bearers.

1. LTE radio bearer: which meets the needs of the radio interface.
2. S1 bearer for the interface S1, between eNodeB and S-GW, in charge of both control plan S1-CP and user plan S1-UP.(21)
3. S5/S8 bearer on the S5/S8 interface, between S-GW and P-GW; S5 is used for non-roaming scenarios where the S-GW is used in the home network while the S8 is used for roaming scenarios.(22)

3.2.1 QoS enforcement

The QoS enforcement points in the LTE core network are in S-GW and P-GW.

- S-GW: performs QoS control at the IP packet level.
- P-GW: provides QoS and policy enforcement at the service level.

When an application requests an EPS bearer, it is established using signaling in the lower layers of the bearers, i.e., S1, S5/S8. The EPS bearers are characterized by the following parameters to be described.

- Quality of Service class identifier [QCI]. It is a value that defines the QoS parameters such as delay, packet loss/error rate. The value assigned to each service may vary depending on the network load and the operator's policies. Therefore, the values described in Table 3 are indicative.
- Guaranteed bitrate [GBR]. Defines the minimum bitrate for a specific service in real-time, guaranteeing QoS. GBR is mainly used to different resource types in LTE, i.e., there are two types of resource types, one with guaranteed bitrates and another without guaranteed bitrates.
- Maximum bitrate [MBR] Defines the maximum bitrate expected for service in consideration..

The types of traffic have been classified into two tables based on whether they are GBR or non-GBR. See Table 3 and Table 4.

Among all the types, we have to highlight signaling, which always has a higher priority, although it does not require a bitrate guarantee since signaling depends on the load, and therefore its bitrate varies. Nevertheless, it requires to have a high priority since it is in charge of establishing the sessions, for example, voice calls setup. Among its QoS, we highlight priority 1, delay 100 ms, and Packet loss rate [PER] 10^{-6}.

Next in the order of priority are applications such as VoIP over LTE, which is VoLTE. With a priority 2, delay 100 ms and PER 10^{-2}. VoIP can be more tolerant to delay than for example real-time communications like V2X messages or Real-time gaming with priority 3, delay 50 ms and PER 10^{-3}.

Table 3. QoS class indentifiers [QCI] with Guaranteed bitrate [GBR] for LTE (23).

QCI	Service Type	Priority	Delay(ms)	PER	Examples service
1	GBR	2	100	10^{-2}	Conversational voice (VoIP)
2		4	150	10^{-3}	Conversational video (live streaming)
3		5	300	10^{-6}	Non-Conversational video (buffered streaming)
4		3	50	10^{-3}	Real-time gaming
65		0.7	75	10^{-2}	Mission critical push to Talk (MCPTT) voice
75		2.5	50	10^{-2}	Vehicle-to-X (V2X) messages

Table 4 QoS class indentifiers [QCI] with Non-Guaranteed bitrate [Non-GBR] for LTE (23).

QCI	Service Type	Priority	Delay(ms)	PER	Examples service
5	Non-GBR	1	100	10^{-6}	IMS signaling
6		7	100	10^{-3}	Voice, Video (live streaming), interactive gaming
7		6	300	10^{-6}	Video streaming(buffered streaming)
9		9	300	10^{-6}	TCP based (e.g. www, email), chat, FTP, p2p file sharing
69		0.5	60	10^{-6}	Mission critical signaling.
70		5.5	200	10^{-6}	Mission critical data grom buffered video streaming, interactive TCP-based uses(Web,email, file sharing)
79		6.5	50	10^{-2}	V2X messages

Up to date, the services with more demand for QoS, in particular, delay were the voice services, but new services have emerged and will emerge in the future. Today, services such as Mission Critical communications have higher priority, but in the future, they may be in the remote control of robotic arms operating in a hospital with the highest priority.

It should be clarified that today the principle of neutrality continues to exist in the network so that no bitrate can be guaranteed for services such as interactive gaming or conversational voice and video unless they are offered as a carrier-grade service therefore if the principle of network neutrality is in use, there is less difference in QoS between these services, as the principle of best-effort rules the traffic.

In summary, OTT services, i.e., open Internet access, are provided by the best-effort approach with minimal QoS and Non-GBR guarantees. On the other hand, GBR can be offered on services that are delivered by controlled IP Networks on the side of the operator, and there is no access to the public Internet, such as VoLTE.

The mechanisms for ensuring QoS are described below. Figure 12 describes the session binding process, and Figure 13 describes the bearer binding where a bearer is created for each different QCI.

LTE-based mobile networks, policy, and charging control [PCC] works on a service data flow [SDF]. Each time an application server requests an EPS bearer, the session-binding process begins to establish the bearer with the required QoS.

Therefore, to offer QoS on mobile networks, it is necessary for the binding of PCC and QoS rules with SDFs. The binding mechanism has three steps described below(2).

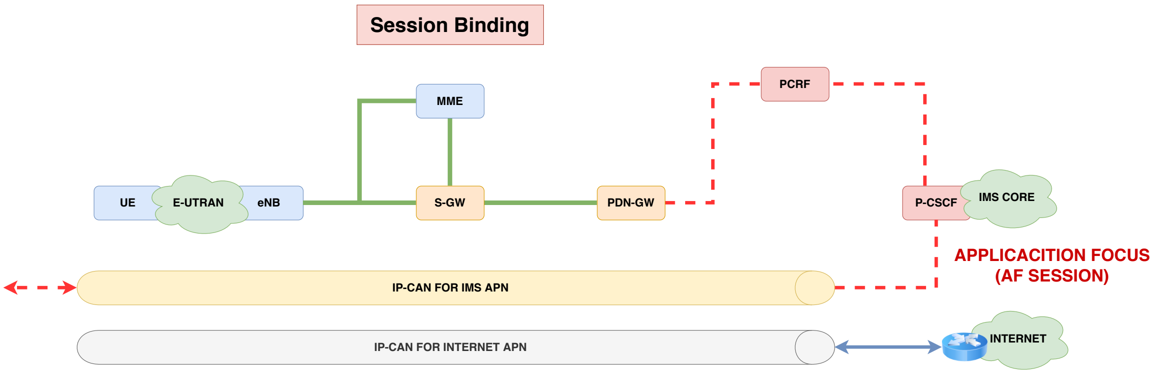


Figure 12. Session Binding process (24).

1. Session binding: It is performed by the PCRF node located in PDN-GW. The IP-CAN [IP Connectivity Access Network] is assigned during the attach procedure of the UE.

For VoLTE calls. The UE requests the setup for VoLTE, the Session Initiation Protocol [SIP] is delivered to the Proxy Call Session Control Function [P-CSCF] with all the information like IP address, destination IP address, ports, protocols.

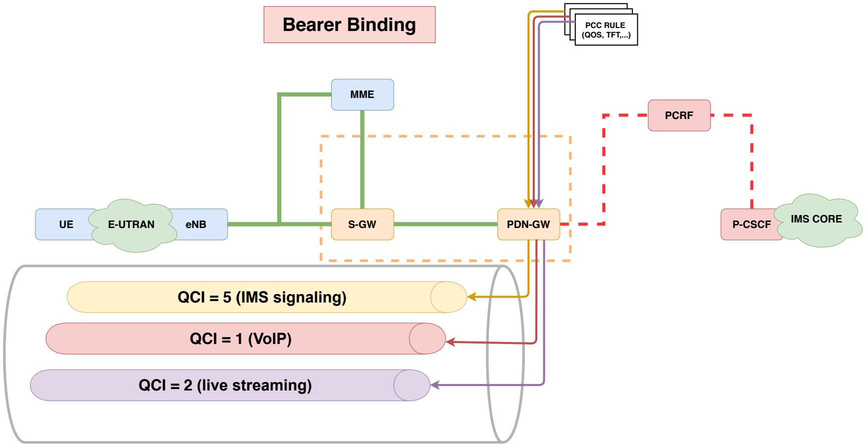


Figure 13. Bearer Binding (24).

2. PCC rule authorization and QoS rule generation (when applicable)
3. Bearer Binding

Bearer Binding means the association of the PCC rule and the QoS rule (if applicable) to an IP-CAN. In VoLTE, the SIP signal flows through the EPS bearer of QCI =5, see Table 3, and there will be additional bearer for the voice Traffic (QCI =1) and the default bearer (QCI=8,9).

The PCC rule contains different parameters that are used for data service control. For example, Flow-Status, QoS. Once this data is sent to PDN-GW, it launches the EPS bearer, sending a "create Bearer RequestQ to the MME. In this process, a bearer is created with QoS parameters such as QCI, MBR.

3.3 The 5G Network Architecture

3GPP officially announced the 5G mobile network with release 15 at the end of 2017. The fifth-generation architecture is an ultra-broadband architecture capable of delivering a theoretical peak of 10 Gbit/s and around 1-2 Gbit/s for individual users. As always it will depend on the capacity of the network and the number of users connected.

3.3.1 5G Performance

The numbers that 5G is going to offer and the new services and technology that are going to come up are quite attractive. This generation has focused on improving the structure of the previous generation but on the same basis, based on IP Networks.

One of the most important theorems in telecommunications theory is the Shannon-Hartley theorem (25), which states that the maximum capacity of a channel (C) (bit/s) depends on the channel's bandwidth (B) and its signal-to-noise ratio (S/N), see Equation 1

Equation 1. Shannon Hartley theorem equation

$$C = B \log_2(1 + \frac{S}{N})$$

In reality, the capacity of the channel that the end-user observes depends on many factors, such as distance to the cell, the size of the cell, the device itself, the speed of movement, obstacles, and the number of users connected to the same cell.

According to Equation 1. Shannon Hartley theorem equation users at the edge of the cell's coverage radius, will receive a worse Signal to noise ratio than users with a direct vision to the cell.

Receiving a better or worse signal-to-noise ratio, it has a direct impact on the modulation scheme that will be used to transmit the data. That is, users with a worse SNR will use a modulation scheme with a lower number of bits per symbol, while users with a good SNR will use a higher number of bits per symbol.

For example, using a quadrature amplitude modulation [QAM] if the SNR is high a 1024 QAM can be used which consists in being able to transport 10 bits per symbol (2^{10} = 1024), while if the SNR is bad 16 QAM will be used, that is to say (2^4 =16) 4 bits per symbol will be transmitted. Therefore using the same radio resources, we have to 10/4 = 2.5 time higher bitrates ratio (2) .

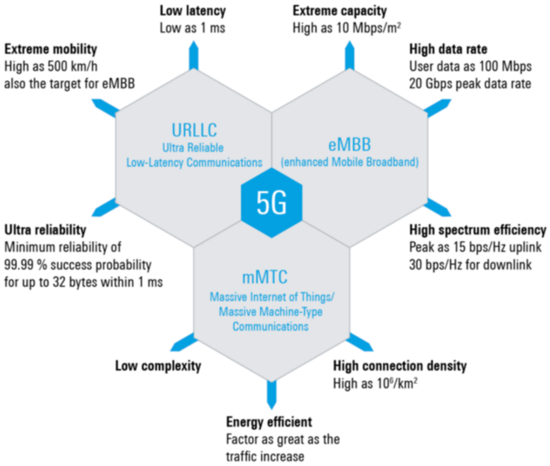


Figure 14. 5G scenarios for IMT-2020 and beyond (26).

As can be noticed in Figure 14, not everything is a high data rate in 5G networks. It also involves ultra-reliable communications and mass communications between very low power consumption devices.

Enhanced Mobile Broadband [eMBB]

eMBB focuses on offering high performance. In order to achieve high performance, it makes use of technologies such as [MIMO] multiple inputs multiple outputs to increase efficiency (bit/s/Hz) and channel capacity (bit/s).
5G networks use higher data rates according to the Shannon Hartley theorem equation. It means increasing the channel's capacity, and one suitable option is to increase the bandwidth. Therefore 5G networks need to use more of the bandwidth of the scarce spectrum available for mobile communications. New frequency bands have been added above 6 GHz, i.e., bands between 24-28 GHz and 86 GHz.
These new bands allow an increase in the capacity and the use of smaller cells that will allow a higher capacity per user, in addition to the possibility of reusing frequencies since the probability of interferences between base stations will be null since the higher frequency there will be a more significant attenuation; therefore, microcells will be able to be used taking advantage of better the spectrum and adding to the QoS that the users are going to receive since to have a higher number of distributed micro cells it will improve the conditions in the edges compared to the use of macrocells..

Ultra Reliable Low-Latency Communications [URLLC]

URLLC services involve new use cases, where there is a small data exchange that can be materialized in reliable and critical communications such as health care monitoring.
URLLC is the technology where the vital function of QoS can be noticed most since it is intended to provide connectivity to critical services over 5G networks. Therefore, offering very strict QoS on 5G technology is a very cutting-edge achievement. Since this technology can save many lives, future examples are the prevention of traffic accidents by avoiding a collision at the very last second or securing emergency service communications even in the most adverse conditions.

Massive Machine Type Communications [mMTC]

Massive IoT will be an extension of the current IoT services. This approach will give access to significant automation in every aspect of our life in professional and personal environments.
5G is also designed to provide service to technologies such as mMTC, whose ambitious goal is to support at least 1 million devices per square kilometer. These devices are known as IoT devices, which have very particular requirements. Among them, we must highlight a very efficient power consumption connection through the Access Network in 5G, NB access, for it has standardized a different architecture intended for mobile communications, reducing the complexity and increasing efficiency.
5G is entering into the market of vertical industries, mainly in health care and automotive offering service to applications such as Vehicle-To-X communications, Ultra-Reliable Low-Latency Communications [URLLC] for remote surgery. As we will look further

ahead, these applications have specific and strict QoS since it is vital to ensure bitrates, jitter, and delay as the leading players in QoS.

3.3.2 Overall 5G architecture

As we have described, 5G has several targets and to be able to offer an excellent service to all of them. Its architecture must be dynamic in order to adjust to its needs. Therefore a new concept is introduced called "Network Slicing," which is crucial in the provision of QoS. Besides, the 5G architecture is a pioneer in introducing the possibility of being compatible with more than one access network of different technology, being able to be from 3GPP [NR-RAN] or not 3GPP as WLAN, Wired broadband.

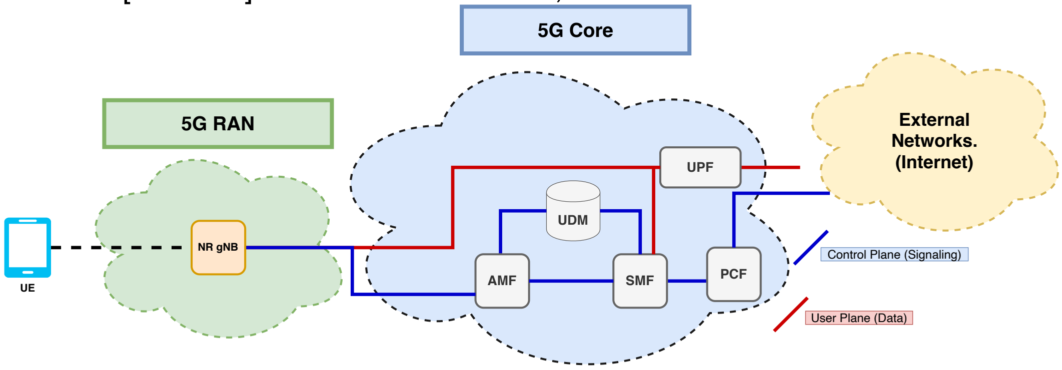


Figure 15. 5G basic arquitecture for mobiles communications (26).

The architecture of the 5G networks is divided into two parts. On the one hand, there is the Core Network [5G CN] and, on the other hand, Radio Access Network in 5G called Next Generation RAN [NG-RAN], which contains the base stations that provide services to the mobile terminals. 5G base stations have different names like gNodeB, NR gNB, or gNB. In this document, it has been used gNB and NR gNB, but all of them refer to the 5G base station.
As in previous generations, the functions are divided into two types, User Planer for data and Control Plane for signaling. The most important parts are described below.(26)

User Plane Function [UPF]

UPF is the anchor point between RAN and UE. When the user moves from one gNB to another, the UPF acts as an anchor point during the handover. Also, UPF deals with the user plane data, and finally, UPF ensures that the QoS enforcement is sending to the right user.

Access and Mobility Management [AMF]

It is in charge of the subscriber mobility determining, for example, if its state is idle or active. Besides AMF provide registration and security enforcements, deciding if the user is allowed in the network, AMF plays a key role in the authentication of the subscriber in the network assigning a temporally ID.

Session Management Function [SMF]

Its role is to establish IP PDU sessions with IPv4 or IPv6 when possible or other types of sessions like a pure ethernet session.

Unified Data Management [UDM]

It is a central repository of subscriber's information, which involves with access authorization. UDM holds security keys, mobility and registration management, tracking where the subscriber is attached.

Policy Control Function [PCF]

One of its main features is that it works under dynamic basic because the network conditions are changing. Depending on the EU's position, PCF has to decide whether it has to be throttled down or even quickly out of the network. Therefore it also makes decisions about the QoS level of each user.
The new elements in the 5G network Core have been described above. However, 5G will coexist with 4G mobile network technologies during the 2020s and beyond. For this reason, 3GPP has defined a structure for interworking between 5G and 4G, see Figure 16.

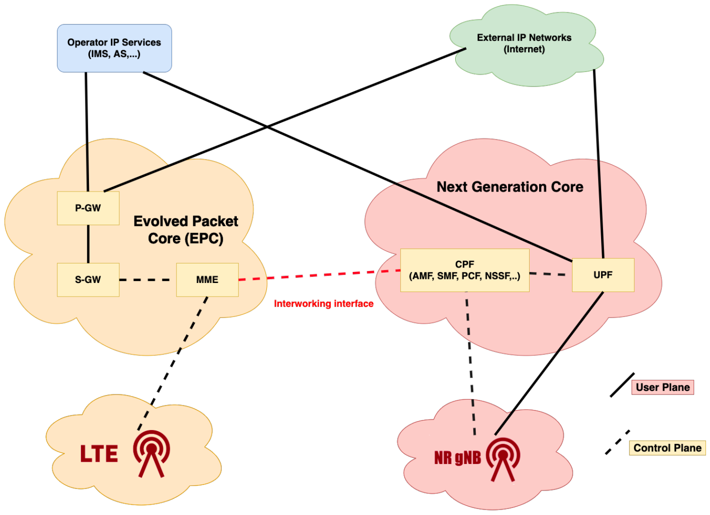


Figure 16. Interworking infraestructure between 4G & 5G Core networks.

The goal is to gradually replace the EPC elements with 5G CN so that new features such as network slicing and network virtualization will become available. Figure 17 describes the different configurations that operators may decide to deploy. Currently, it is only possible to deploy non-standalone technologies so in the first deployments in 2018 5G capabilities began to be offered only by installing 5G RAN working in parallel with 4G RAN (option 3), later 5G CN was implemented with dual connectivity between 4G & 5G RAN (option 4 & 7), and finally, it is expected that in the next years Standalone 5G capabilities (option 2) will be definitively deployed.

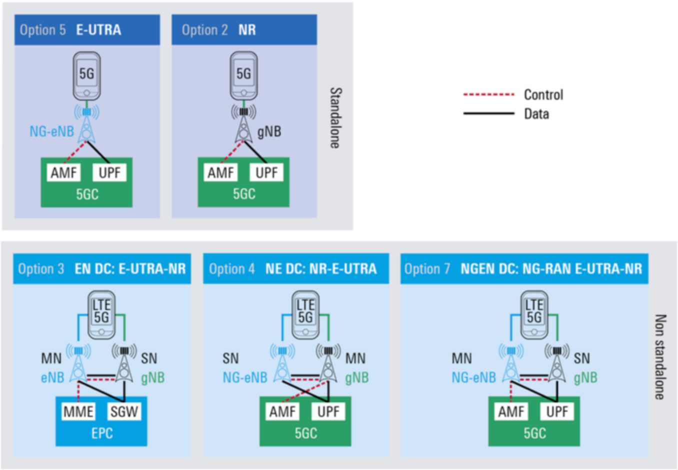


Figure 17. 5G connectivity options (26).

3.4 QoS in 5G Networks

3GPP has established the first parameters for QoS in 5G networks in Release 15. At the same time as it was made to define the objectives of LTE in IMT-Advanced. The ITU has established in IMT-2020 the outline objectives for 5G networks, below are described both the new objectives for the fifth generation and a comparison with the previous generation. Table 5 Objetives in IMT-Advanced (LTE) and IMT-2020 (NR 5G) defined by ITU, from (2)

	IMT-Advanced	**IMT-2020**
Minimum peak bitrate	Downlink: 1 Gbit/s Uplink: 0.05 Gbit/s	Downlink: 20 Gbit/s Uplink: 10 Gbit/s
Bitrate experienced by individual mobile device	10 Mbit/s	100 Mbit/s
Peak spectral efficiency	Downlink: 15 bit/s/Hz Uplink: 6.75 bit/s/Hz	Downlink: 30 bit/s/Hz Uplink: 15 bit/s/Hz
Mobility	350 km/h	500 km/h
User plane latency	10 ms	1 ms
Connection density	100 thousand devices per km^2	1 million devices per km^2
Traffic capacity	0.1 Mbit/s/m^2	10 Mbit/s/m^2 in hot spots
Frequency bandwidth	Up to 20 MHz/carrier (up to 100 MHz aggregated)	Up to 1 GHz (single or multiple frequency carriers)

To meet these objectives, besides increasing the transmission channels' capacity, increase the density of base stations, and use higher frequencies and greater bandwidth.

Support for QoS in 5G networks also needs to be improved, which began in Release 15 with the introduction of new QoS flow identifiers (5QI). Table 6 describes the most relevant new 5QI as the new QoS flow identifiers.

Table 6 5G Indicator (5QI) for Delay Critical GBR Resource type (2).

5QI	Resource type	Priority	Delay budget (ms)	Packet loss rate	Default maximum data burst volume	Targeted services
10	Delay Critical GBR	11	5	10^{-5}	160 bytes	Remote control
11		12	10	10^{-5}	320 bytes	ITS (intelligent transport systems)
12		13	20	10^{-5}	640 bytes	Other delay critical services
16		18	10	10^{-4}	255 bytes	Discrete automation

A new resource type category (Delay Critical GBR) oriented to URLLC has been introduced, although release 15 is oriented to eMBB, it is expected that in releases 16 and 17 more parameters will be introduced for URLLC and mMTC.

In the GBR categories. there is no change, the same parameters are maintained as in LTE and LTE advanced described in Table 3.

The QoS in 5G is based on the QoS flows model as described in Figure 18, There are small differences from the model described above in the 4G network section.

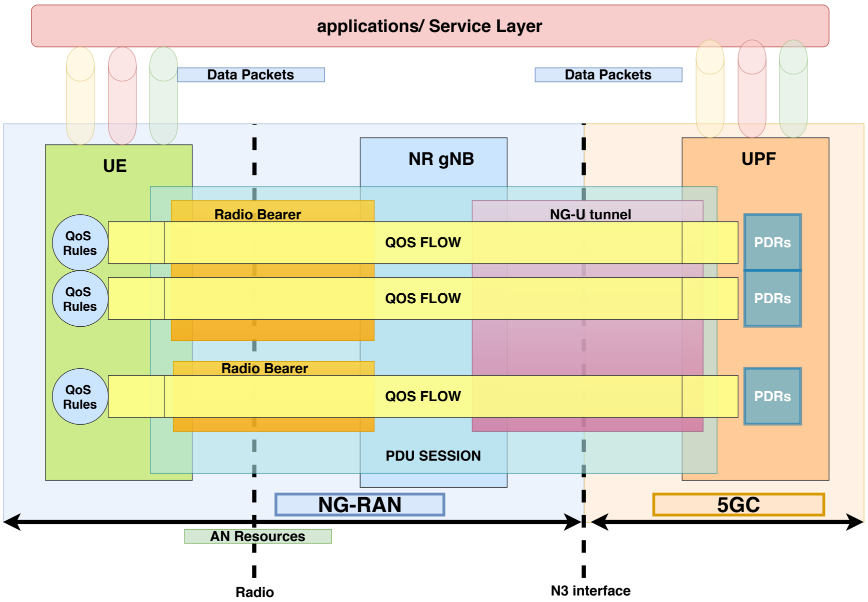


Figure 18. 5G QoS flow architecture (27).

The main idea is that when the PDU session is established, different QoS flows are created that carry similar traffic in terms of Class Indicators set in the QoS template. Therefore all traffic mapped with the same QoS flow will receive the same treatment in terms of scheduling policy, queue management, prioritization, and rate allocation, and so on.

In the N3 interface, each QoS flow is identified by its id, in this case, 5QI. In the PDRs (Packet detection rule), the UL and DL packets are associated with their correct transport through all the protocols and interfaces overall.

In NG-RAN, it is established that for each UE at least one data bearer (default bearer) and other possible additional bearers depending on the established QoS flows. Finally, to transport the information over the air NG-RAN associating UL and DL QoS flows with data bearers and to differentiate them from other UE that are connected, the QoS flows of each UE are mapped with their corresponding PDU session.

Finally, 5G NR also supports guaranteed flow bit rates (GBR QoS flows) and QoS with non-guaranteed flow bit rate as in the previous generation. However, as a new feature "reflective QoS" has been introduced which means that UE uses the same UL QoS parameters as those obtained through DL flow since one of the most significant improvements in 5G is the increase in uplink performance (UL), so similar QoS rules can be used due to this symmetry.

3.4.1 Network Slicing

One of the most significant transformations has taken place in the core of the 5G network, as it has been designed to support a range of services with different characteristics and features such as mobile broadband, vehicle to vehicle, machine-type communications, smart home, Smart grid and IoT. So to have a core that adapts to all these applications using the same hardware has created the concept of "Network Slicing”.

Network Slicing provides the capability to have different logical networks using shared hardware, Figure Figure 19 shows Network slicing defined in IMT 2020. Each logical network is known as a network slice.

Three service type [SST] are defined, defined in (28) .

Table 7 Types of Slice services.

Slice Type	SST value	Description
eMBB	1	Slice suitable for handling 5G high data rates in applicactions like streaming of high quality video, fast large file transfer.
URLLC	2	Supporting ultra-reliable low latency communications for applications including industrial automation (remote)
MIoT	3	Enabling the support of a large number and high density of IoT devices efficiently and cost effectively.

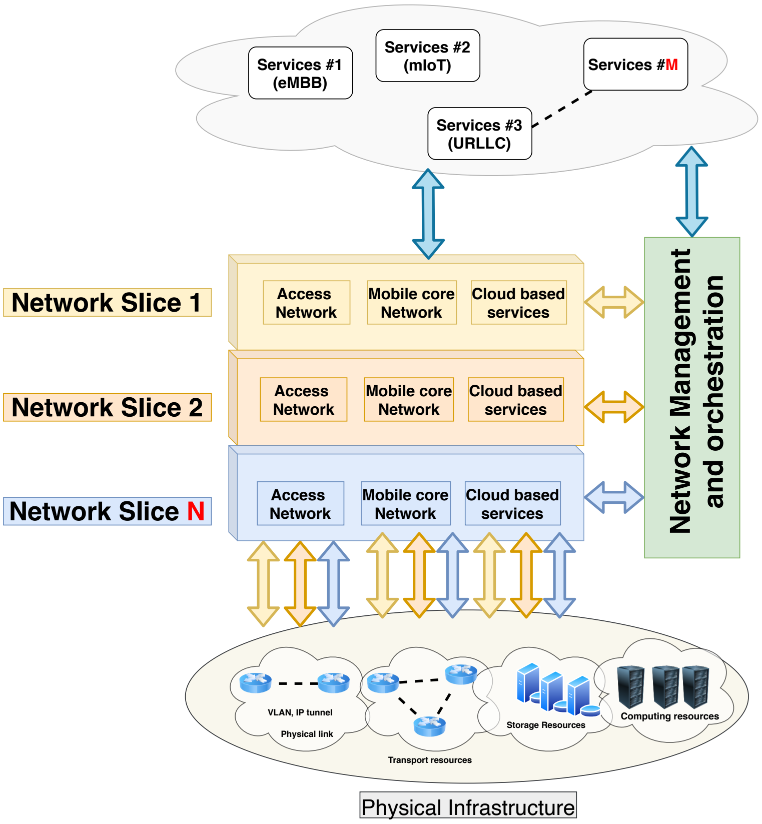


Figure 19. Network slicing defined in IMT-2020 (2).

It is necessary to adopt a solution to give a better service in terms of QoS to each of these applications due to the wide variety of different services with different characteristics. One solution is to virtualize certain elements of the Network core that in previous technologies were hardware. These virtualized elements are AMF for control plan elements, UPF for user plan elements, UDM for subscriber management and PCF for Policy control.

Virtualization allows the creation of separate networks within the core specifically designed to serve particular services with very defined requirements in terms of QoS, so we could have a network slice designed to handle large data loads and a specific QoS for example for video-streaming (eMBB). It is also possible to dedicate another network slice to connect a large number of IoT devices, offering low consumption connectivity Massive Internet of Things (mIoT) and finally dedicate a network slice to offer very low latency and high reliability for critical services (URLLC). It is also possible to dedicate slices to offer the same service but with different QoS depending on the options of the subscriber.

In addition, the IMT-2020 also describes the possibility of offering non-3GPP connectivity as Wi-Fi or fixed Access. For example, in the future, the terminals will be able to connect to Wi-Fi and the mobile network at the same time and use these simultaneously and take advantage of each technology. i.e., making a voice call the terminal connects to the mobile network with a QoS guarantee, but at the same time it can be downloading a large file through Wi-Fi taking advantage of the higher bandwidth.

4 MEASURING QOS IN A LABORATORY ENVIROMENT

In this chapter, the results obtained in the radio laboratory of the research group 5G Test Network Turku "5GTNT" will be presented.

The main aim of these measurements has been to study the software available for these types of measurements, as well as to apply the theoretical knowledge acquired during the accomplishment of this Thesis. Although the results obtained are not relevant beyond applying the theoretical knowledge in practice, although it will be useful to draw conclusions when using tools such as Qosium and G-NetTrack Pro to facilitate measurements in future projects or to analyze the performance during the deployment of the private 5G network in the laboratory.

4.1 Radiolab LTE Network architecture.

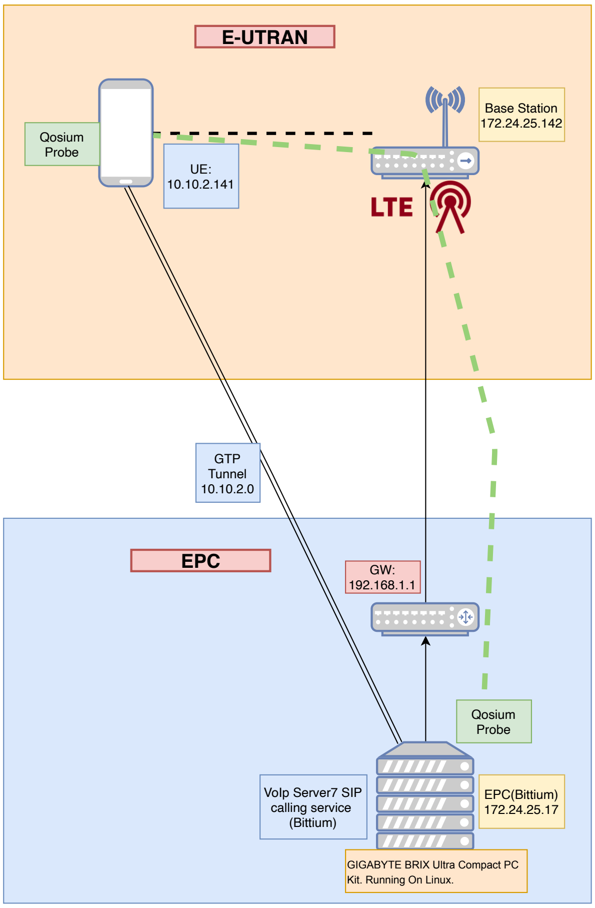


Figure 20. Radiolab Network architecture under test

As shown in Figure 20, the network used to carry out VoIP and video-streaming QoS measurements consist of a basic LTE network with a very basic version of the EPC from Bittium. This EPC is running on a mini PC "Brix IoT" from GIGABYTE. In the E-UTRAN part, a LTE Base Station has been used and as the UE, two types of Android terminals have been used; Samsung S8 and Essential phone are depicted in Figure 21.

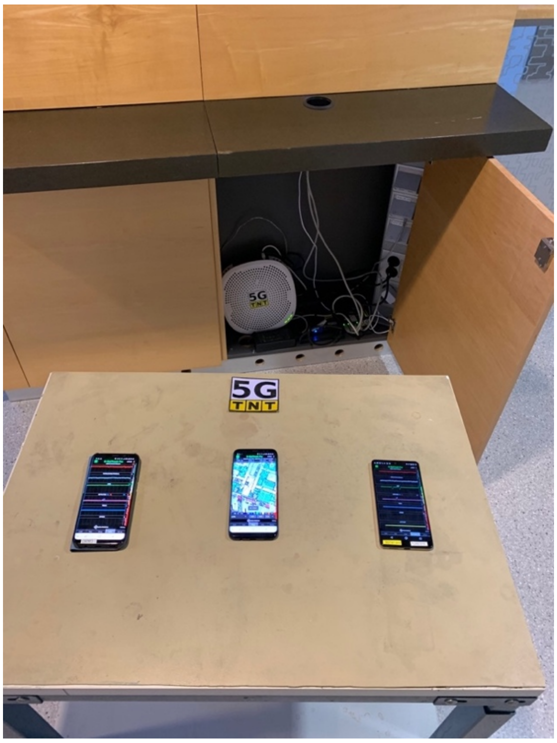


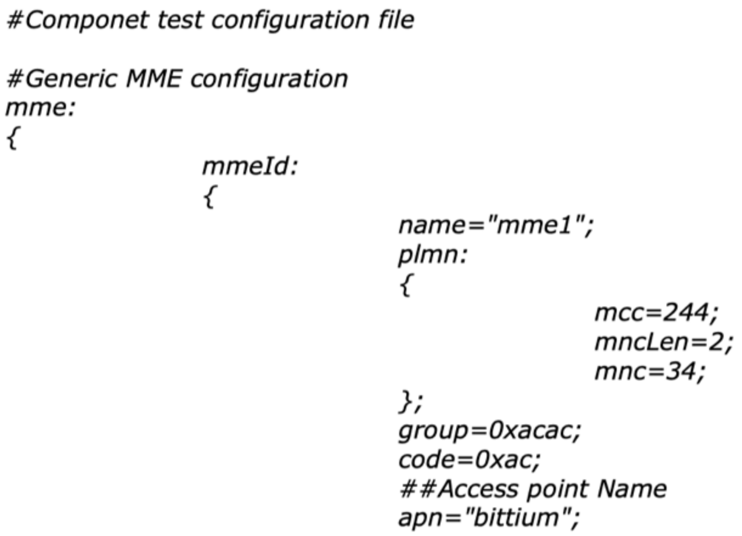
Figure 21. User Equipment and Base Station used to perform the QoS measurements

4.2 EPC

On the Debian based Linux mini PC, the Evolved Packet Core [EPC] is running to handle payloads (data traffic) between the EU and eNodeB. The EPC software has very low requirements. It can work on a low-end modem day computer but not in on Raspberry Pi. The EPC has been used runs with minimal LTE network core, for more information on LTE network core see 0.

Configuration

For the configuration of the EPC there are two files that we must configure, to configure the interfaces we must go to the directory /etc/network/interfaces where among other configurations we can define the use of DHCP, in this case, it has been deactivated for convenience in order to carry out measurements. To configure parameters such as Mobile Country Code [MCC] and Mobile network code [MNC], go to the directory /etc/ecp/ and open the file "config.cfg", MCC and MNC are depicted in Figure 22.

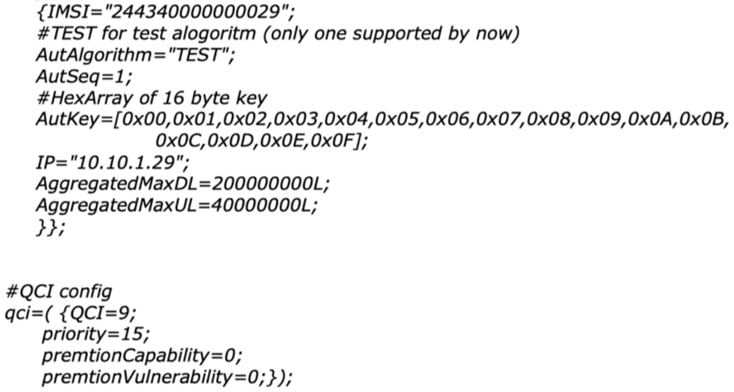


```
#Componet test configuration file

#Generic MME configuration
mme:
{
                mmeId:
                {
                                name="mme1";
                                plmn:
                                {
                                                mcc=244;
                                                mncLen=2;
                                                mnc=34;
                                };
                                group=0xacac;
                                code=0xac;
                                ##Access point Name
                                apn="bittium";
```

Figure 22. MME configuration parameters

These parameters must match the SIM-Card, but in order to have access to the network, you need to configure the Access Point Name [APN] profile in the terminal.
In addition, we can also define some parameters for QoS as QCI, see section 0 to assign a priority type depending on the traffic, we can even limit the throughput of UL and DL, Figure 23 shows UE configuration parameters.



```
   {IMSI="244340000000029";
   #TEST for test alogoritm (only one supported by now)
   AutAlgorithm="TEST";
   AutSeq=1;
   #HexArray of 16 byte key
   AutKey=[0x00,0x01,0x02,0x03,0x04,0x05,0x06,0x07,0x08,0x09,0x0A,0x0B,
                0x0C,0x0D,0x0E,0x0F];
   IP="10.10.1.29";
   AggregatedMaxDL=200000000L;
   AggregatedMaxUL=40000000L;
   }};


#QCI config
qci=( {QCI=9;
    priority=15;
    premtionCapability=0;
    premtionVulnerability=0;});
```

Figure 23 UE configuration parameters, QCI, DL and UL maximum throughtput

4.2.1 TVS

Within the Bittium EPC based software, "TVS Call Services" is a Session Initiation Protocol [SIP] back-to-back user agent [B2BUA] server with registration service. This means that in order to make use of the VoIP calls, you need to register the terminals on the server first.

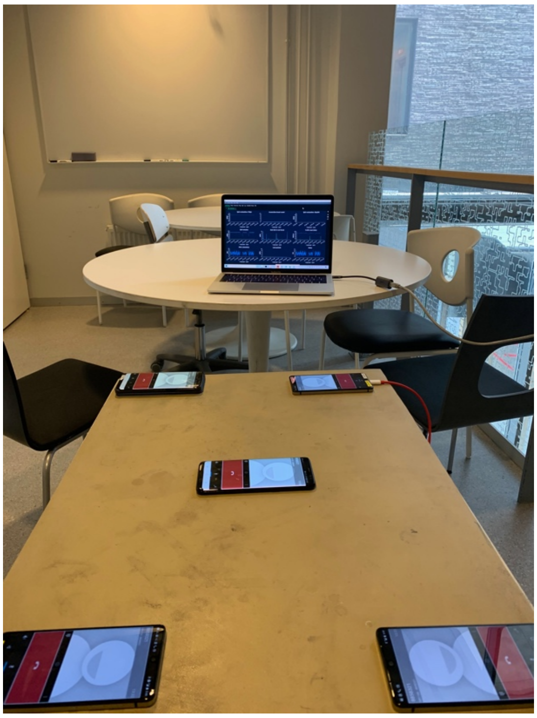


Figure 24. VoIP group call

In addition to allowing calls between two terminals, there is also the possibility of making group calls, as shown in Figure 24.
To carry out this in the configuration file, we must define the numbers associated with each EU. In this case, the numbers assigned were 112,107,110, 100, and 105. When making the call, it is possible to establish a priority between 1 and 5 where 5 is the maximum priority, for example, to call terminal 107 with the maximum priority you must dial 885107 (88YXXX) where Y is the priority and X is the number in question.

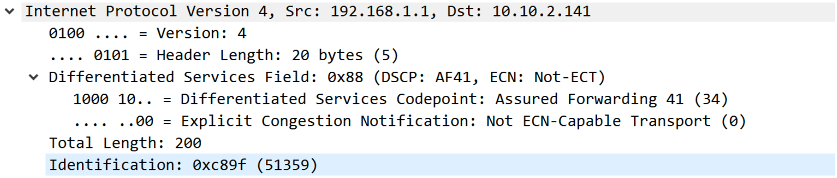
4.3 LTE Base Station

An LTE base station has been used among the parameters we highlight. The frequency band used was band 40 or TDD 2300, where Time Division Duplex is used, this means that the same frequency is used for DL and UL at different time slots.
The bandwidth used is 10 MHz, and the carrier power was the minimum possible in this case, 17 dBm.

4.3.1 QoS parameters in LTE Base Station

In the BTS site manager configuration section, we can customize how the traffic to be transmitted to the terminals will be managed; therefore, we can apply QoS between BTS and UE.
In this case, it is possible to apply QoS with Differentiated Services [DiffServ] more details in 0 2.6.2 Differentiated Services.

In Figure 25 is described the DSCP codes where rank with higher priority is 48-55 and 56-63 destined for network Control traffic, and the less priority is 0-7 destinated for best-effort traffic.



```
⌄ Internet Protocol Version 4, Src: 192.168.1.1, Dst: 10.10.2.141
    0100 .... = Version: 4
    .... 0101 = Header Length: 20 bytes (5)
  ⌄ Differentiated Services Field: 0x88 (DSCP: AF41, ECN: Not-ECT)
      1000 10.. = Differentiated Services Codepoint: Assured Forwarding 41 (34)
      .... ..00 = Explicit Congestion Notification: Not ECN-Capable Transport (0)
    Total Length: 200
    Identification: 0xc89f (51359)
```

Figure 25. DSCP in VoIP

4.4 Qosium measuring software for VoiP and Videostreaming QoS measures.

Qosium software from Kaitotek Oy is a passive tool designed to perform end-to-end QoS measurements. In this case, it has been used to perform VoIP and Video streaming measurements to analyze the performance of an LTE network in a laboratory environment. The traffic introduced by Qosium in the network is small and does not alter the results. It also allows us to see in real-time the network behavior and to identify in real-time if something is not working correctly(29).

Two tools have been used to carry out this type of measurement in this thesis.

- On the one hand, Qosium Probe, which is a lightweight measurement agent that can be installed in the elements of the network that it has to be analyzed, for example, in Routers, switches, mobile devices, computers, even IoT devices. We can carry out single-point measurement with one Qosium probe or two-point measurements with two Qosium Probes. (Single-point measurements yield less information than two-point measurements).
- On the other hand, the Qosium Scope is an analyzer that allows us to control and parameterize in detail the type of traffic to be analyzed. Besides being able to see the results in real-time, save the Pcap results, average results for later viewing or exporting them to, for example, Matlab.

More information about this tool can be found on their website at (30) and in its manual.

4.4.1 VoIP settings in Qosium

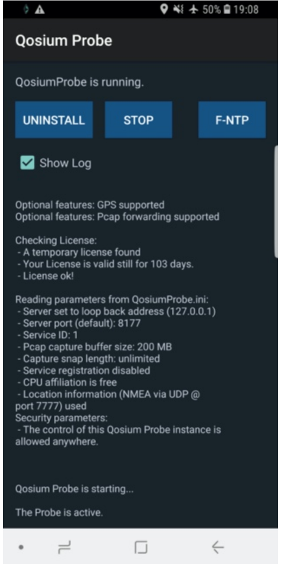
To perform end-to-end VoIP QoS measurements with Qosium on 5GTNT RadioLab, one of the Qosium Probes was placed on the Ubuntu mini PC running the SIP server and the other Probe in the EU, allowing a complete end-to-end analysis of the VoIP traffic.

Basic settings for VoIP measurements

1. Start Running Qosium Probes.

- In Linux, it can be started as a service with the command *sudo systemctl start QosiumProbe*
- In Windows, after the installation in the programs folder it can find a shortcut named *Run Qosium Probe directly* just run it.
- In Android Phones, the installation could be laborious because the Qosium app needs superuser rights to have full access to the system. In order to install Qosium APK, it is needed a rooted phone.

Rooting an android phone, it is the way the skip the system's restrictions. It is highly recommended that beforehand installing Qosium in Android. Check the android model software version and manufacturer because the process may vary and the difficulty.
One drawback of Qosium for Android is that not every model phone and software version can be rooted, Figure 26 shows Qosium probe running in Android.



QosiumProbe is running.

```
Optional features: GPS supported
Optional features: Pcap forwarding supported

Checking License:
 - A temporary license found
 - Your License is valid still for 103 days.
 - License ok!

Reading parameters from QosiumProbe.ini:
 - Server set to loop back address (127.0.0.1)
 - Server port (default): 8177
 - Service ID: 1
 - Pcap capture buffer size: 200 MB
 - Capture snap length: unlimited
 - Service registration disabled
 - CPU affiliation is free
 - Location information (NMEA via UDP @
port 7777) used
Security parameters:
 - The control of this Qosium Probe instance is
allowed anywhere.


Qosium Probe is starting...

The Probe is active.
```

Figure 26. Qosium Probe running in Android

2. Once we have the Probes running, open Qosium Scope and select single or two-point measurement from the emerging window or top bar View> settings wizard.
3. Add the IP of the primary probe and the secondary probe respectively

- In this case, the IP of the main probe was 172.24.25.17, which is the IP of the EPC in the Tuas network where the SIP server was running.
- As a secondary Probe was selected one Samsung S8 rooted with a fix IP 10.10.2.141
- -Then click connect and if there is some issue to establish the connection verify that there is ping between the IP address.
- Select the capture interface as it can be noticed in Figure 20. The Qosium streamflow was going through the interface or gateway 192.168.1.1. In that case, that was the interface selected. Qosium shows a star next to the interface address, which means that this interface has been used recently, so it could be easier to identify the interface in question.

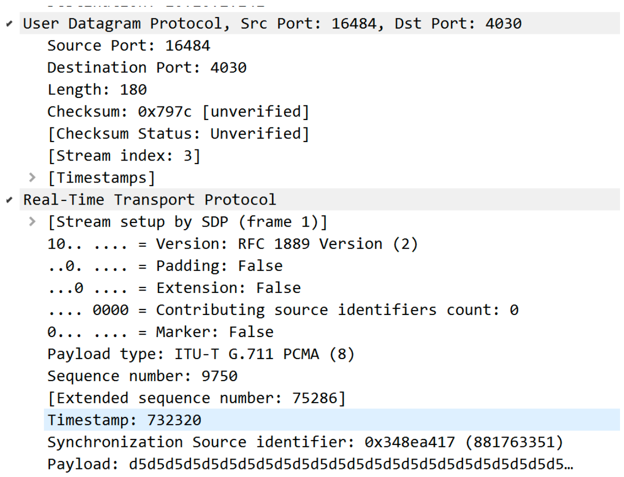
4. Go to the "measurement" tab to set the filter parameters.

- In some cases, it could be challenging to know the right parameters to filter the traffic we are trying to analyze.
- To start deciding which are the right parameters a useful tool is Wireshark

```
9199 96.265070     192.168.1.1          10.10.2.141          RTP       200 PT=ITU-T G.711 PCMA, SSRC=0x348EA417, Seq=9750, Time=732320
```

Figure 27. Wireshark VoIP traffic capture

- - Figure 27 shows that the interface in use was 192.168.1.1 and the UE Ip (IP destination) was 10.10.2.141, and the type of traffic was Real-Time Protocol RTP, and the codec is available for audio was G.711and PCMA.



```
⌄ User Datagram Protocol, Src Port: 16484, Dst Port: 4030
    Source Port: 16484
    Destination Port: 4030
    Length: 180
    Checksum: 0x797c [unverified]
    [Checksum Status: Unverified]
    [Stream index: 3]
  › [Timestamps]
⌄ Real-Time Transport Protocol
  › [Stream setup by SDP (frame 1)]
    10.. .... = Version: RFC 1889 Version (2)
    ..0. .... = Padding: False
    ...0 .... = Extension: False
    .... 0000 = Contributing source identifiers count: 0
    0... .... = Marker: False
    Payload type: ITU-T G.711 PCMA (8)
    Sequence number: 9750
    [Extended sequence number: 75286]
    Timestamp: 732320
    Synchronization Source identifier: 0x348ea417 (881763351)
    Payload: d5d5d5d5d5d5d5d5d5d5d5d5d5d5d5d5d5d5d5d5d5…
```

Figure 28. Raw information from Wireshark capture VoIP traffic

In Figure 28 is depicted useful information from Wireshark VoIP capture Traffic. This information is very useful to decide what it is the filter we should apply in the measurement tab. There are different options to set the filters in the measurement tab, next it is described two examples that get the same results.

- *ip src 172.24.25.17 and not port 8177 || ip dst 10.10.2.141 and not port 8177*

This is option one. The IP source is the Ip from the EPC, and the IP destination is the IP from the UE. However, it may not be working as well as the next one because we will measure all the traffic between the UE and the EPC, not only the VoIP traffic. Also, notice that we have to discard the Qosium traffic between the probes, so it has to be indicated ”not port 8177,” which is the port that Qosium uses by default.

- *Port 16484*

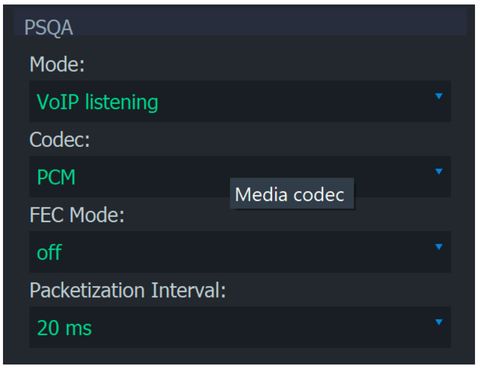
The second option to perform VoIP traffic is more straightforward than the first one. It is using the port where all the traffic data from VoIP call is going through. Notice that the VoIP Server uses a range of ports destined to TCP and UDP traffic so the port will change every time. Using tools like Wireshark can be useful to identify the used port every time. The back draw is that we cannot start measuring before starting the call.

5. Setting the QoE tab.

Qosium also has the option to measure QoE using two methods. On the one hand, General QoS Measure [GQoSM] algorithm is not scientifically proven but can be sufficient to define how the user experience is being received. However, to measure QoE scientifically, there is the PSQA method. In this option, Qosium allows obtaining QoE from VoIP and video streaming traffic. In this case for the VoIP traffic can be only listening or conversational; in the case of listening to, the available codecs are Pulse Code Modulation [PCM] and Global System for Mobile [GSM], therefore in the configuration file of the SIP server must be set as default codec Pulse Code Modulation A-Law [PCMA] to make proper measurements. However, for conversational VoIP traffic, only the Speex codec is available.

PCMA refers that A-Law is the logarithmic scale used for sizing the distance between sampling steps. There are two scales for PCM, A-Law [PCMA] and μ-law [PCMU], more information can be found in (31)

In Figure 29 is depicted the Pseudo Subjective Quality Assessment [PSQA] for measuring QoE more information can be found in this paper (32) and in Figure 30 is depicted the logs from TVS where it can be appreciated that default codec in using is PCM.



PSQA

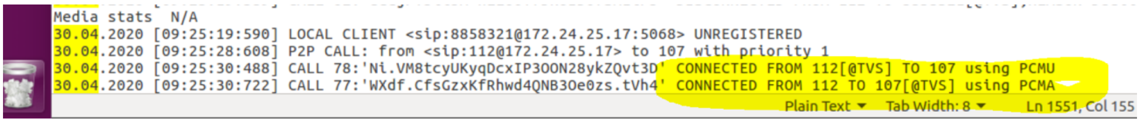
Mode:
VoIP listening

Codec:
PCM

FEC Mode:
off

Packetization Interval:
20 ms

Figure 29. QoE PSQA model



```
Media stats  N/A
30.04.2020 [09:25:19:590] LOCAL CLIENT <sip:8858321@172.24.25.17:5068> UNREGISTERED
30.04.2020 [09:25:28:608] P2P CALL: from <sip:112@172.24.25.17> to 107 with priority 1
30.04.2020 [09:25:30:488] CALL 78:'Ni.VM8tcyUKyqDcxIP3OON28ykZQvt3D' CONNECTED FROM 112[@TVS] TO 107 using PCMU
30.04.2020 [09:25:30:722] CALL 77:'WXdf.CfsGzxKfRhwd4QNB3Oe0zs.tVh4' CONNECTED FROM 112 TO 107[@TVS] using PCMA
```

Figure 30. Example of PCM codec utilization.

After this configuration, it is possible to start measuring in real-time the traffic generated in VoIP. Figure 31 is depicted as an example of a real-time measurement of VoIP traffic on Tuas Network.

Figure 31. Real-Time QoS VoIP traffic measured with Qosium

Figure 31 shows QoS metrics such a Delay, Packet Loss, QoE with PSQA, QoS samples (packet/s), jitter, and traffic load (bit/s). These measures were taken on the move by performing a VoIP call. It is normal to see those small fluctuations caused when the signal is weak. In the results section, it can see more results exported and plotted with Matlab.

4.4.2 Setting Qosium for Video-Streaming measurements.

To make Qos measurements in video-Streaming everything explained above is equally valid, making the relevant changes such as exercising in the corresponding places of the network the Qosium Probes, modifying the IPs, as well as the filters. however, we will highlight some small differences.

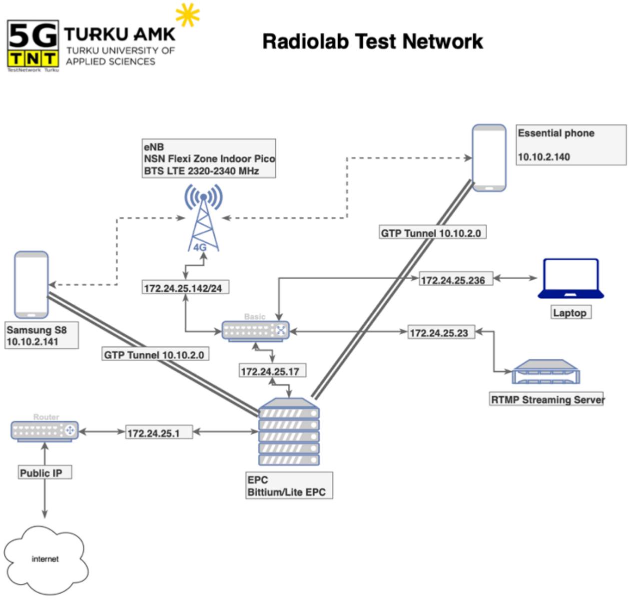


Figure 32. RadioLab Test Network for Video-streaming QoS measurements

1. According to Figure 32 as a primary Probe, it should establish the RTMP server and as a secondary Probe the UE. In this case, in order to connect the probes from end to end, the IP addresses had to be added manually in the RTMP server's IP routes table with the following command:

- *sudo ip route add 10.10.2.141 via 172.24.25.17*

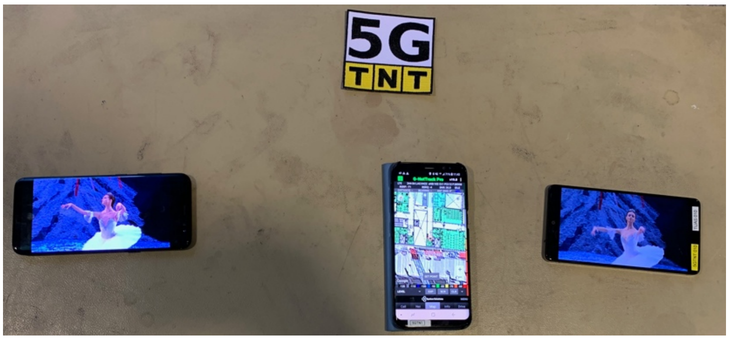
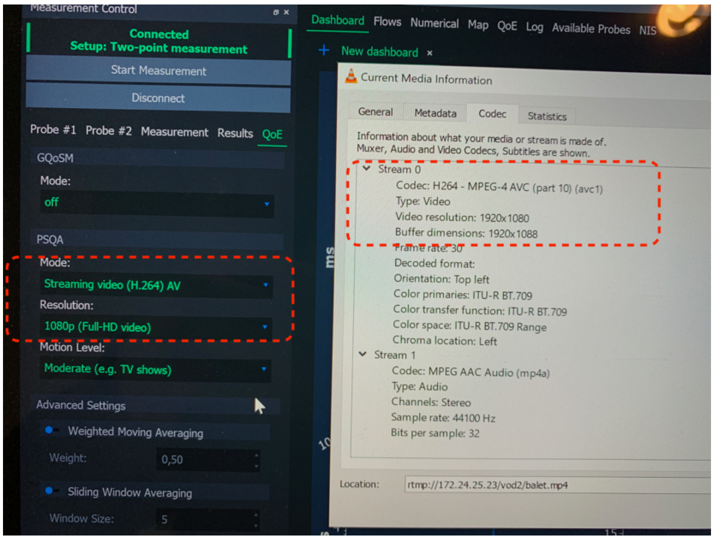


Figure 33. Measuring Video-Streaming QoS in Tuas Network

2. Another important point to consider when defining the parameters to measure video-streaming is the protocol used by the video-streaming server, it is depicted in Figure 34.



Connected
Setup: Two-point measurement

GQoSM
Mode: off

PSQA
Mode: Streaming video (H.264) AV
Resolution: 1080p (Full-HD video)
Motion Level: Moderate (e.g. TV shows)

Weighted Moving Averaging
Weight: 0,50
Sliding Window Averaging
Window Size: 5

Information about what your media or stream is made of.
Muxer, Audio and Video Codecs, Subtitles are shown.

Stream 0
Codec: H264 - MPEG-4 AVC (part 10) (avc1)
Type: Video
Video resolution: 1920x1080
Buffer dimensions: 1920x1088
Frame rate: 30
Decoded format:
Orientation: Top left
Color primaries: ITU-R BT.709
Color transfer function: ITU-R BT.709
Color space: ITU-R BT.709 Range
Chroma location: Left

Stream 1
Codec: MPEG AAC Audio (mp4a)
Type: Audio
Channels: Stereo
Sample rate: 44100 Hz
Bits per sample: 32

Location: rtmp://172.24.25.23/vod2/balet.mp4

Figure 34. Video-streaming codec information

As it can be observed taking into account these details, it is very simple and easy to start taking real-time QoS measurements. This example is very basic, but the Qosium tool allows us to make very professional measurements at all levels of complexity, so it is highly recommended for research environments and industry users.
For more details on how to take measurements with Qosium software, in Appendix I, there is detailed information on how to take measurements with Qosium software at the end of this document..

4.5 G-NetTrack Pro app for VoIP and VideoStreaming QoS measures.

"G-NetTrack Pro is a wireless network monitor and drive test tool for Android OS devices. It allows monitoring and logging of mobile network parameters without using specialized equipment" (33).
G-NetTrack Pro has been the other tool that has been used to study QoS in VoIP and Video streaming in Tuas Network. It has been especially interesting to take indoor and outdoor measurements in the ICT-City building since it allows a visualization in real-time of the received data as signal power, Download Rate [DL Rate], Bandwidth [BW] or Signal to Noise Ratio [SNR], being able to make conclusions of the QoS received in the different points of the map.
Another feature to highlight is the possibility of using a terminal as a central server that controls other terminals remotely via Bluetooth; it can take measurements at the same time of up to 8 devices. For example, Figure 35, it is well illustrated this utility in the middle terminal did not obtain correct measurements of DL rate [it was made to show that in case of malfunction of one terminal, it is possible to have the results from others devices].
In addition, having multiple probes logging data at the same opens the possibility to export all the data, perform the mean between results from different sources, and get more precise results, excluding fluctuations.

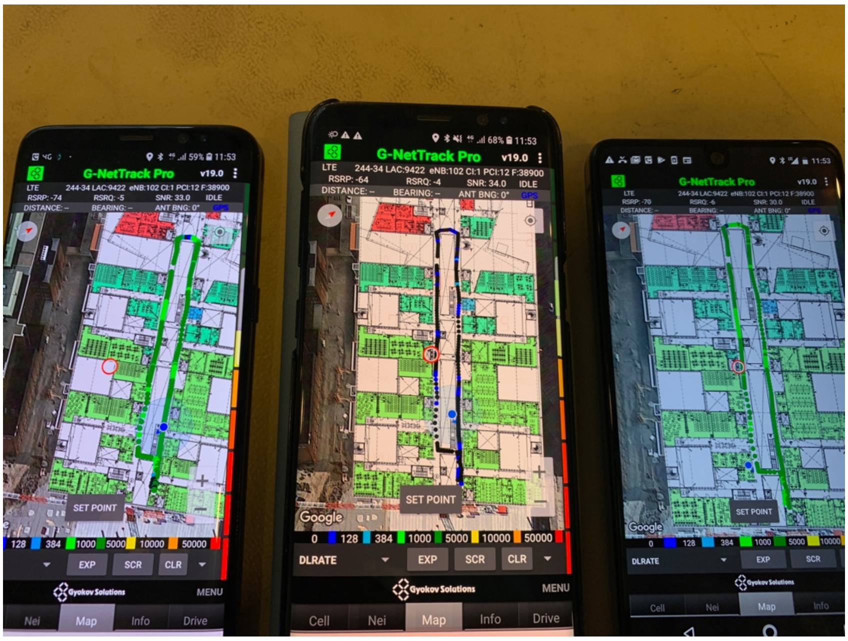


Figure 35. G-NetTrack Pro indoor mode while performing QoS VoIP measurements

Figure 36 and Figure 37 show outdoor QoS measurements using the G-NetLook web viewer. It can be found here (34) .

MEASUREMENT INFO

OPERATOR	Bittium!
MCC	244
MNC	34
TECH	4G
LAC	9422
NODE	102
CELLID	1
PCI	12
LEVEL	-88
QUAL	-4
SNR	26.0
CQI	13
LTERSSI	-75
ARFCN	38900
DL BITRATE	2305
UL BITRATE	12
ACCURACY	3
LOCATION	G
ALTITUDE	41
HEIGHT	2
CONNECT	M
ID	11
TIMESTAMP	2020.04.30 14.01.36

Figure 36. Outdoor QoS measurements with G-NetTrack Pro

Outdoor measurements are automated through the use of GPS. If the signal is lost or is not very accurate, measurements can be taken manually as in indoor mode. Without a doubt, this tool works very well to have QoS data displayed on both an indoor and outdoor map, plus it has a unique feature that allows visualizing the measurements through street view in google maps, depicted in Figure 37. More information on how to take measurements in the second appendix of this document or in the manual that can be consulted at (33) .

Figure 37. Street View mode with QoS measurements

Figure 38 it is shown an example of indoor QoS measurement results. For indoor measurements, where the GPS signal is weak and not accurate. It is needed to perform measurements activating indoor mode. So the measuring process will not be automatically done instead of that we have to set point manually.

To activate the indoor mode, go to (⁝), then settings and indoor, and click on Indoor Mode to activate. Then it the map section, it will appear “set point”.

Also, we can add an indoor floor plan to perform indoor measurements. In Appendix 2 can be found more information explaining how to perform measurements with G-NetTrack Pro.

5 RESULTS

Next, it will be shown the final results obtained in the LTE network of the Radiolab of the research group 5GTNT in Turku University of Applied Sciences [TUAS], the main objective of these results has been to learn the advantages and disadvantages of the software described above, this way it has been possible to develop some specific guides of how to take measurements in a research environment that will be useful both at present for 4G and 5G networks when trying to measure QoS in mobile networks in different applications that are necessary at the time of carrying out projects.

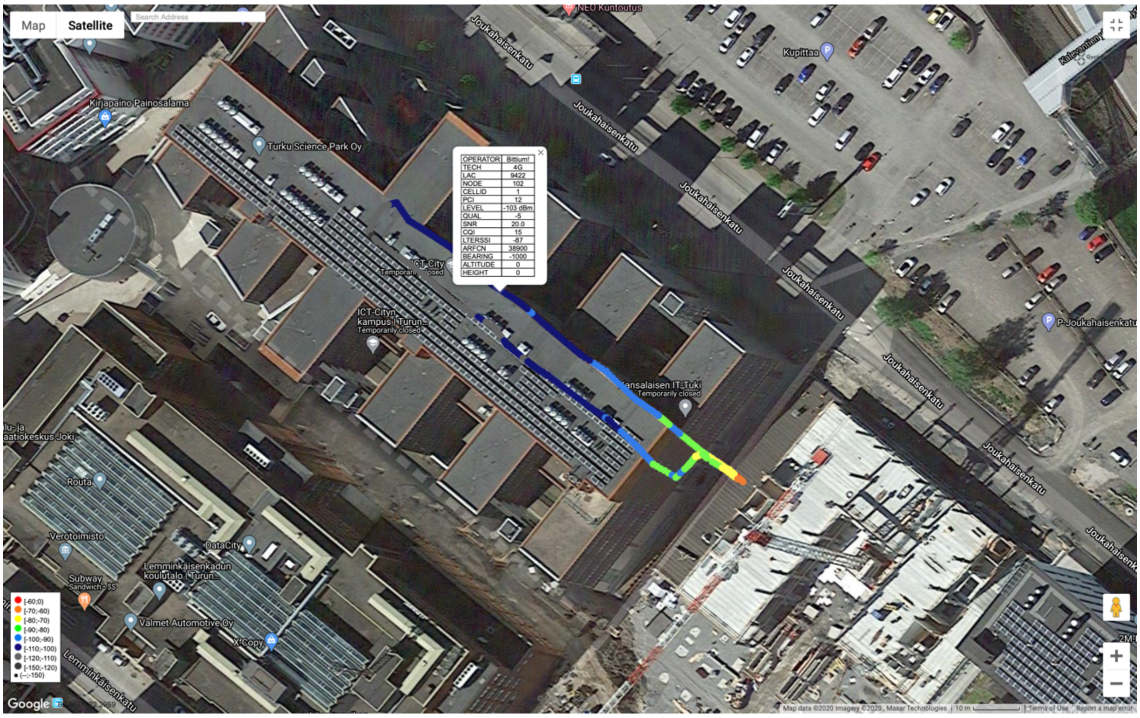
The results measured with Qosium and G-NetTrack Pro are shown together on the one hand in a VoIP call and, on the other hand, in a video-streaming display. These two applications offer us multiple metrics for QoS measurements. Here we have exposed the most interesting and useful in this case. The QoS metrics measured by Qosium are Traffic Load, Jitter, and Delay. While the QoS measures measured by G-NetTrack Pro are Signal Level, SNR and Traffic Load.

In Figure 38 and Figure 45 are shown the indoors measurements performed with G-NetTrack Pro, however, although in the mobile application it allows using indoor maps see Figure 35, in the web viewer that has been used to analyze the measurements it is not possible, to be able to analyze measurements with an indoor map it needs another application called G-NetView Pro.

Among all the metrics exposed, we can compare the traffic load measured by Qosium and by G-NetTrack Pro. We can see that in average terms, we receive an average bitrate of 80 Kbit/s in both measures for VoIP and 1500 Kbits/s for Video-Streaming. The need for different QoS rules for VoIP and Video Streaming has become proven.

These metrics have been taken using LTE (4G) technology. It should be noted that while Qosium does not depend on the technology used, as it can be run on a wide range of devices. However, G-NetTrack Pro is a mobile application that depends on the operating system restrictions and its compatibility with new technology is limited to the technology that the terminal supports and to the developer's updates, in this case, some tests have been done with commercial 5G networks, and the application was not fully compatible this can be a limiting factor when using this application.

5.1 QoS measured in a VoIP Call with Qosium and G-NetTrack Pro.



OPERATOR	Bittium!
TECH	4G
LAC	9422
NODE	102
CELLID	1
PCI	12
LEVEL	-103 dBm
QUAL	-5
SNR	20.0
CQI	15
LTERSSI	-87
ARFCN	38900
BEARING	-1000
ALTITUDE	0
HEIGHT	0

Figure 38. Indoor route in ICT City measuring QoS VoIP

Figure 38 shows the bird's eye view of the measurements taken around the first floor while taking VoIP QoS measurements. It can be seen how the colors reflect the received signal strength. These results could be used to decide whether to install another indoor base station to provide better coverage in areas where the signal is shown to be weak. Figure 39 and Figure 40 show the received signal level and the signal to noise ratio, respectively. In both graphs, it can be correctly appreciated how the measurements vary depending on the terminal position in the plant, reaching a minimum of -120 dBm of power in the received signal about to be dropped the call.

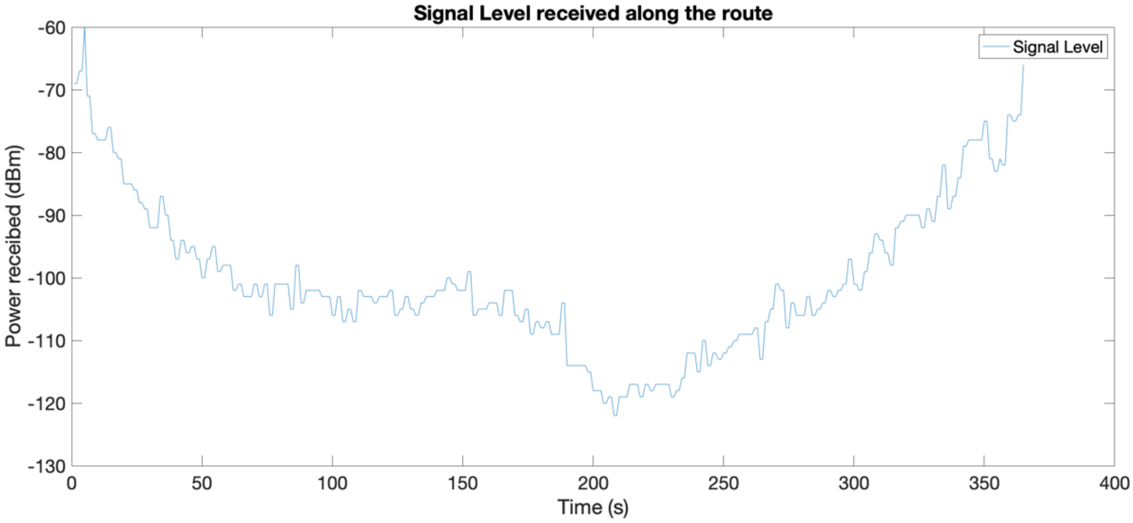


Figure 39. Signal Level measured with G-NetTrack Pro in a VoIP call

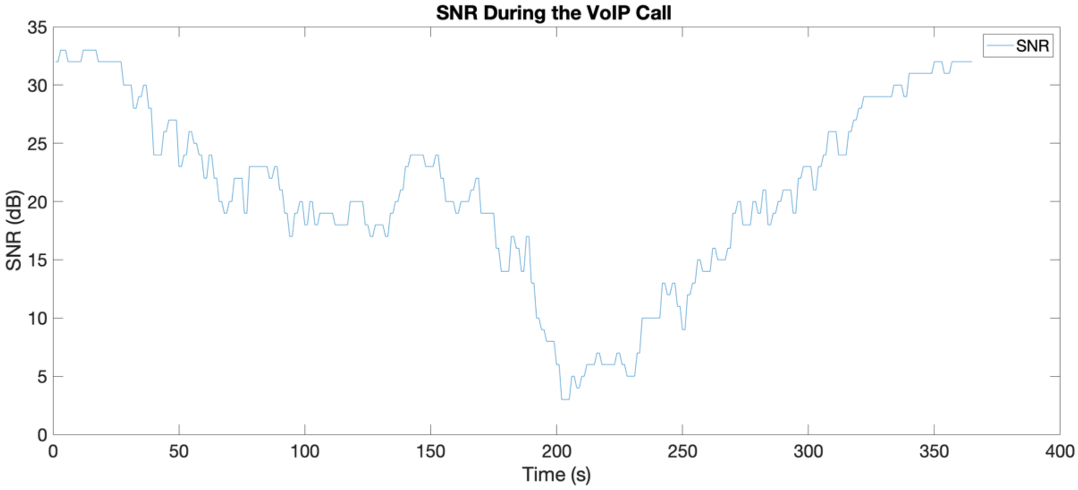


Figure 40. SNR measured along the route with G-NetTrack Pro in a VoIP Call

Figure 41 and Figure 42 show the comparison between Qosium and G-NetTrack Pro by measuring the traffic load performance. In average terms, it is shown that the measurements are similar, measuring about 90 Kbit/s. However, Qosium shows a higher sensitivity measuring the Kbit/s. Depending on the type of measurements, it can be interesting to have a higher sensitivity in the measurements with the cost of a longer time to prepare the measurement environment.

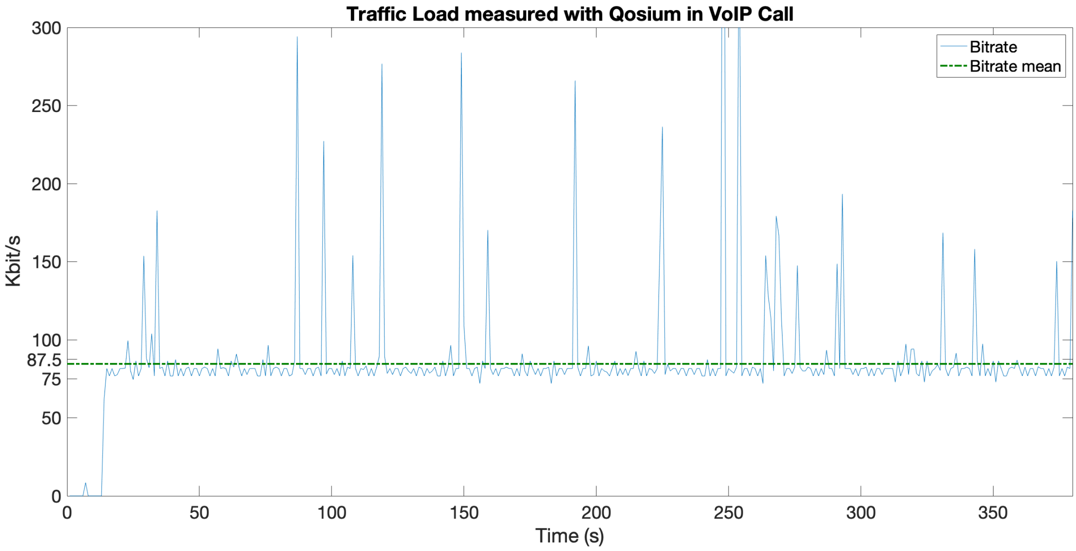


Figure 41. Traffic Load VoIP Call Results measured with Qosium

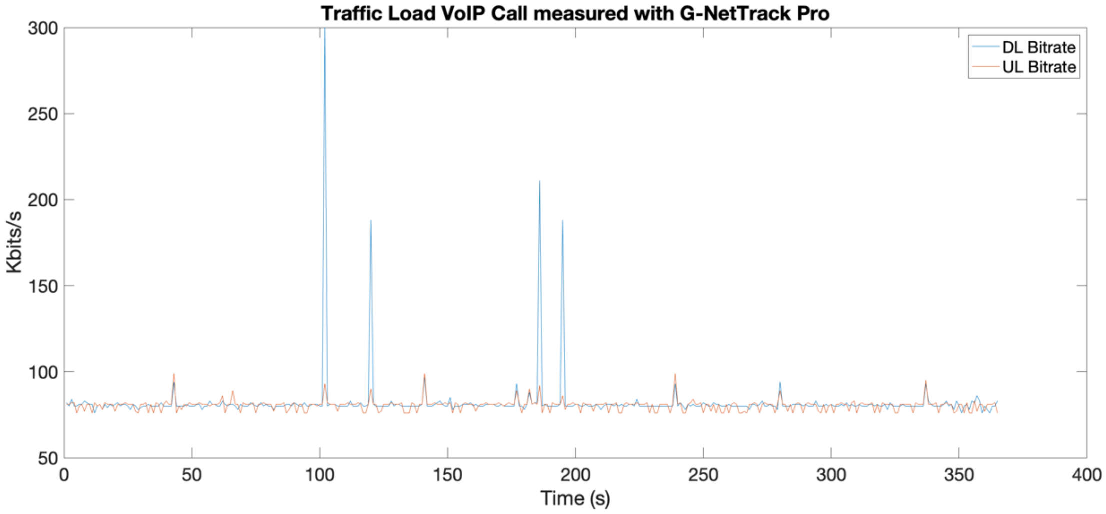


Figure 42. Traffic Load VoIP Call Results measured With G-NetTrack Pro

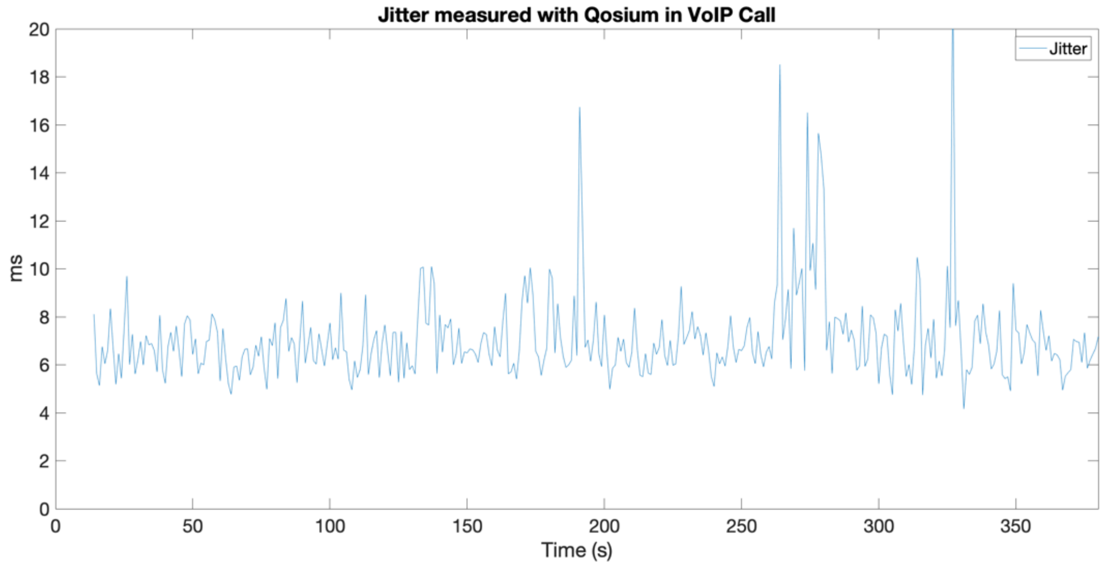


Figure 43. Jitter measured in VoIP Call

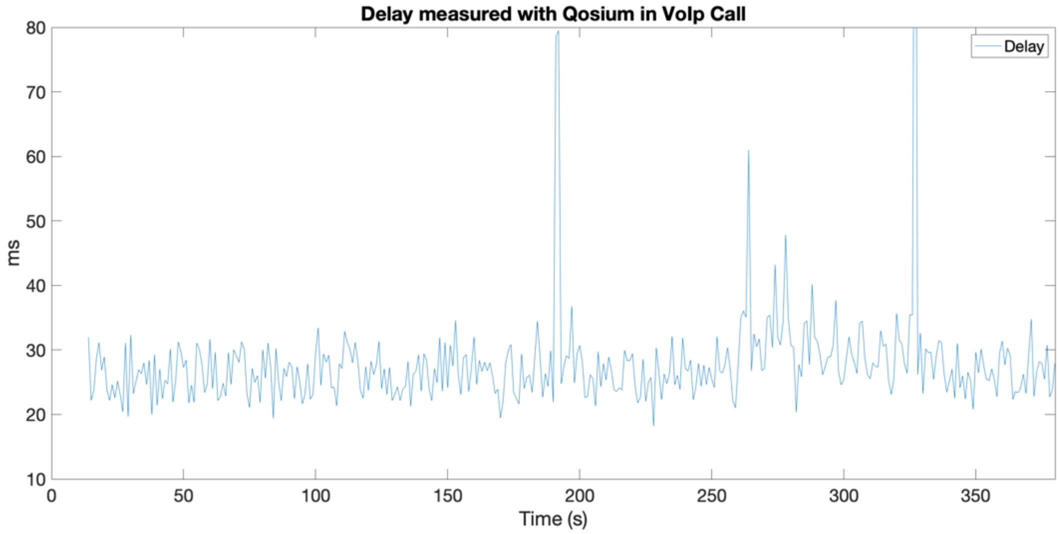
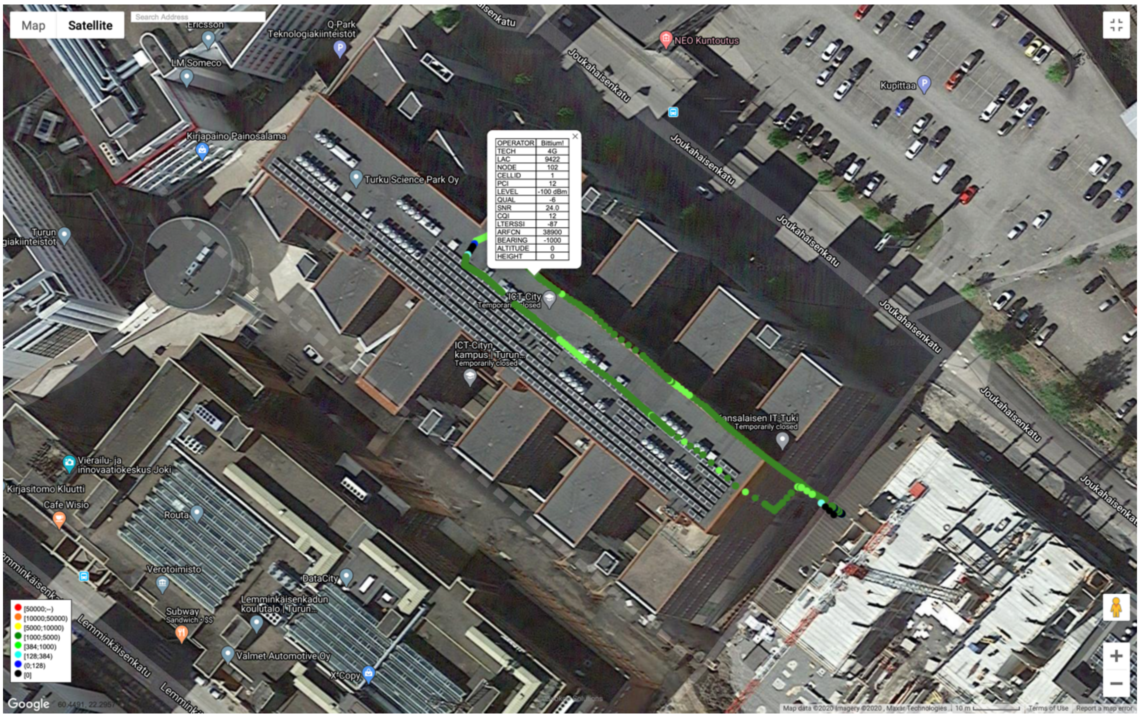


Figure 44. Delay measured in VoIP Call

Figure 43 and Figure 44 show the jitter and delay, respectively. Both measures are quite reasonable in terms of performance needed for a VoIP call. They were having a jitter of about 6 ms and a delay of about 25 ms. These measures fully meet the QoS requirements for VoIP calls allowing for a reasonably good user experience that is perceived by the user.

5.2 QoS measured in a Video-Streaming with Qosium and G-NetTrack Pro.



OPERATOR	Bittium!
TECH	4G
LAC	9422
NODE	102
CELLID	1
PCI	12
LEVEL	-100 dBm
QUAL	-6
SNR	24.0
CQI	12
LTERSSI	-87
ARFCN	38900
BEARING	-1000
ALTITUDE	0
HEIGHT	0

Figure 45. Indoor measurements performed with G-NetTrack Pro watching a Video Streming along the building

Figure 45 shows the bird's eye view of the ICT-CITY building. On this occasion, the DL bitrate received has been measured in motion along the entire floor. It can be seen how it practically remains constant.

Figure 46 and Figure 47 show the received signal level and the signal to noise ratio respectively measured along the path of the first floor. It is interesting to see how the signal peak is not at the closest to the base station, but we have to go a few meters forward to find it. A minimum of -120 dBm is again given in the signal. On the other hand, there is a significant variation in the SNR due to the distance and the obstacles between the terminal and the base station.

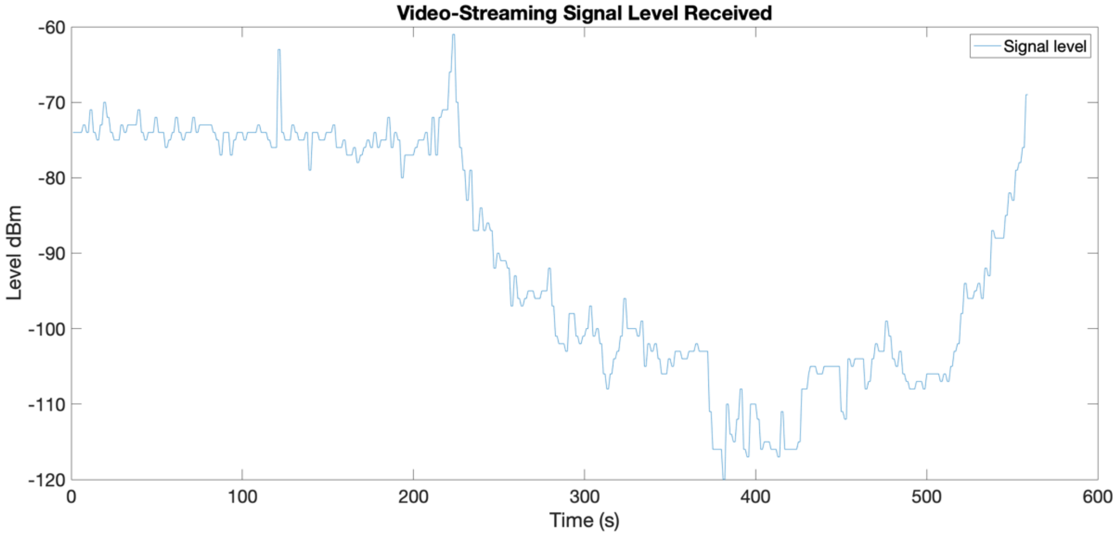


Figure 46. Signal measured with G-NetTrack Pro during visualization of a video-streaming

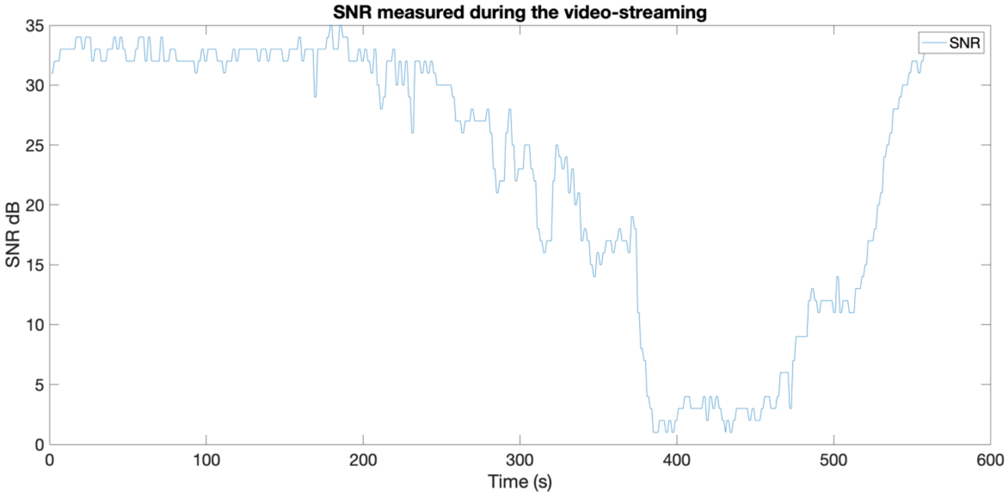


Figure 47. SNR measured with G-NetTrack Pro during the visualization of a Video-Streaming.

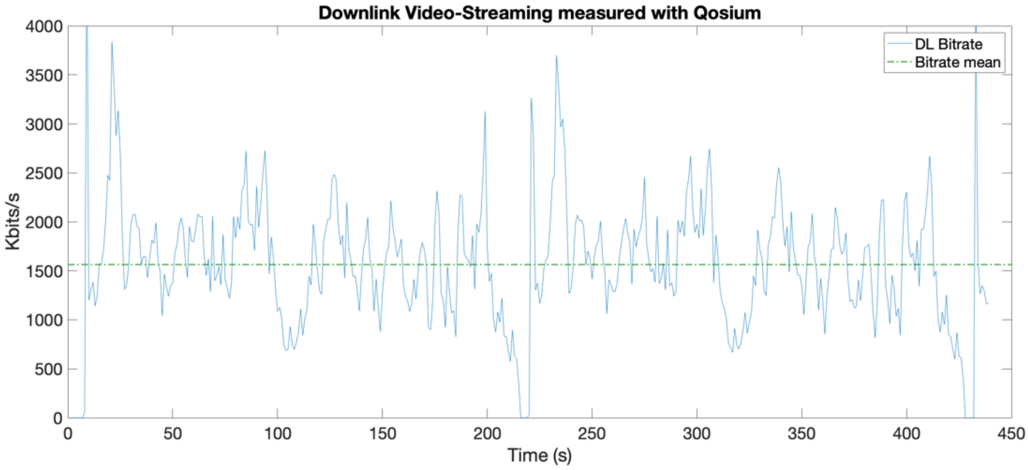


Figure 48. Traffic Load measured with Qosium during the visualization of a Video-Streaming

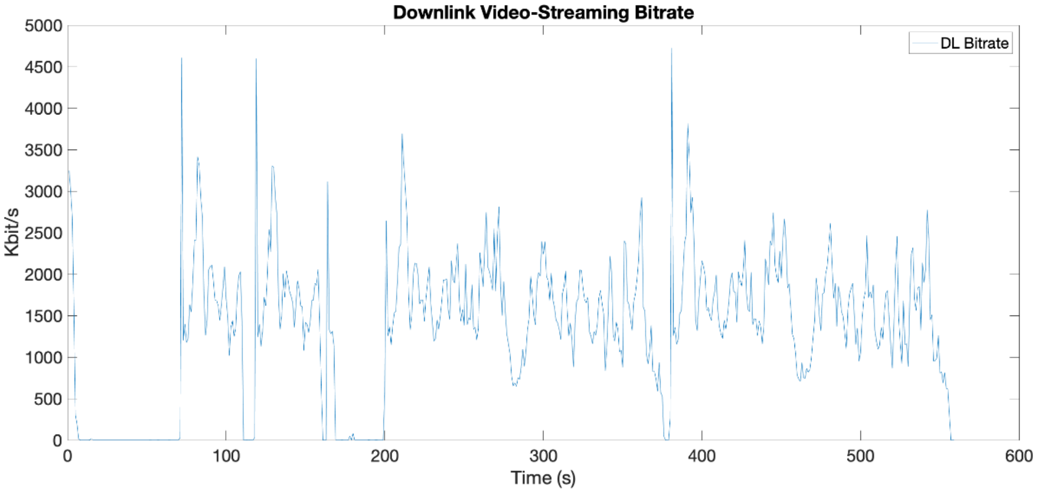


Figure 49. Traffic Load measured with G-NetTrack Pro during the visualization of a Video-Streaming

Figure 48 and Figure 49 show again a comparison between the performance measured by Qosium and G-NetTrack Pro measuring DL bitrate.

Both graphs are similar in terms of timing, as it is very complicated to start two measurements of the same traffic simultaneously with two different applications.

On average, the DL bitrate is 1550 Kbit/s. These measurements were performed in movement, so due to signal variations, it can see fluctuations in the bitrate.

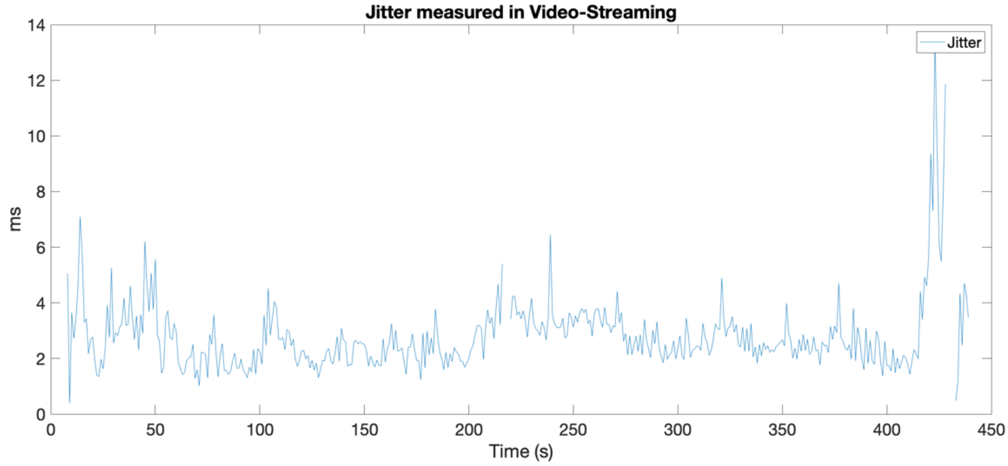


Figure 50. Jitter measured with Qosium during the visualization of a Video-Streaming

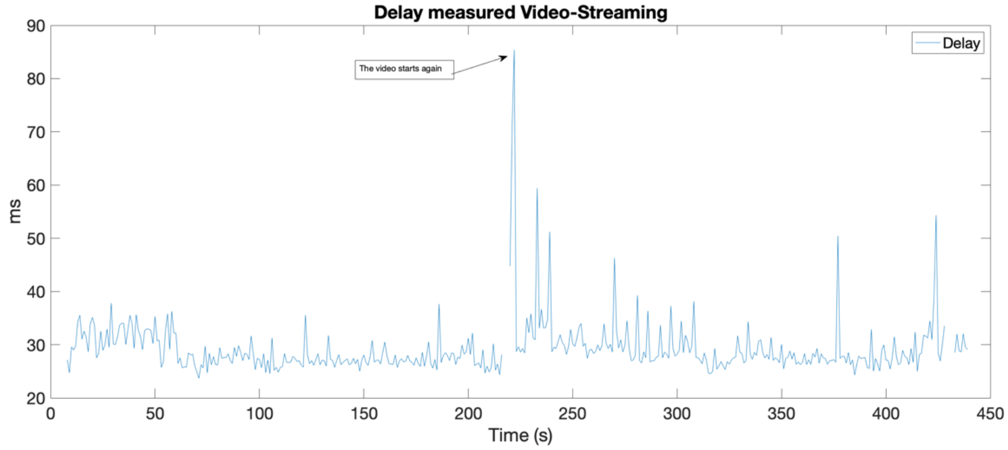


Figure 51. Delay measured with Qosium during the visualization of a Video-Streaming

From Figure 50 and Figure 51, It can be observed at a general level that Qosium offers much more precise and detailed measurements due to its much more complex functioning as well as the time needed to establish the set up to measure with Qosium. On the other hand, the measurements offered by G-NetTrack Pro are less precise, but it is possible to start taking measurements very quickly so to draw some general conclusions can be useful and if later it is necessary to go deeper Qosium can be used to draw the definitive conclusions. Therefore, these two tools can be perfectly complementary and offer different measures, some of them more focused on performance such as Bitrate, delay, jitter, Qos samples in the case of Qosium and in the case of G-NetTrack Pro it is more focused on metrics of the physical layer such as signal level, SNR, among others.

6 CONCLUSION

This thesis has introduced the most technical aspects that are nowadays behind the QoS offered by mobile communications in its massively deployed technology. Before there was 4G and now 5G, that is still in a premature state but that without any doubt promises many benefits as far as communications are concerned.

The thesis has demonstrated that QoS is not something simple to implement or develop and that it takes a long time to implement the changes that guarantee the different end-to-end service requirements. One solution that will facilitate the implementation of QoS is Network Slicing, which has been introduced 5G technology as a novelty.

Network Slicing will enable better QoS in the desired services, setting different slice with different priorities, delays, and bitrates that will allow dedicated QoS in URLLC, eMBB, and mMTC applications that until now have used a common mobile communications infrastructure. QoS measuring tools will be used to test and show the different performances of the network slices.

This work aims to relate the theory behind the study of QoS with the practical work in a research laboratory carrying out various QoS measurements in a 4G network. The objective of the results is not to highlight their relevance but to show the capacity that exists today to measure QoS in mobile applications using two of the available tools; namelyQosium and G-NetTrack Pro.

As the results section has shown, both applications are good options for measuring QoS. Each of them has its advantages and disadvantages, Qosium has a much more professional approach to research and industry environments, allowing more complex and diverse measurements and higher sensitivity in the results than G-NetTrack Pro. Meanwhile, G-NetTrack Pro offers less complicated results and only for mobile terminals, but its easy implementation is a plus for taking preliminary measures.

These tools have shown the advantages and disadvantages of performing QoS measurements. Both the thesis and the appendices explain in more detail how to perform measurements in order to be able to use this document as a small guide to take QoS measurements, as well as to understand the technical part that is behind that can be useful to discover problems in the network.

It would have been interesting to be able to take QoS measurements in 4G and 5G networks to show the most significant difference and capacity between both. Unfortunately, it has not been possible t to take the measurements in 5G networks. However, the 5G network of the 5GTNT research group is expectedto start being tested, and this document will be a starting point to take QoS measurements in the future projects that will be carried out.

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How to Perform Measurements With Qosium

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***Abstract*—In this document, It is explained how to perform measurements using Qosium, real-time passive software. It is shown results from video-streaming measurement**

***Index Terms*—Qosium, QoS, QoE, 4G**

I. INTRODUCTION

Qosium is a powerful passive tool meant for measuring in real-time the quality of service (QoS) and quality of experience (QoE) in applications, e.g., VoIP, video streaming, or video conferencing. In this document, it is focused on how to perform video-streaming and video conferencing measurements, also some general tips and recommendations are given.

II. FIRST STEPS

¡

Before running Qosium Probe and Qosium Scope, one has to define what is the topology of the network that we want to measure, e.g., Fig.1. Qosium allows us to make measurements in every point in the network, but not all the point will have the same performance or in some of them will be very difficult to perform measures while other will be easier. For this reason, it is essential to have in mind what nodes will be our desirable measuring points.

Qosium allows two-point measurement (two Qosium probes running) or single point measurement(one Qosium probe running), and with Qosium Scope, we can visualize the measurements in real-time. Qosium Probe can run in Windows, Linux, and Android (rooted phone is needed), so it should not be a problem to choose the node in the network. Qosium Scope is available for Windows and Linux.

III. SETTING QOSIUM PROBE AND SCOPE

Once we have decided where we are going to measure, the next step is to start Qosium Probe and Qosium Scope. if you need to install Qosium check more details in [1]

A. Start Qosium Probe

1) Windows: run as administrator 'Run Qosium Probe directly'

2) Linux: in terminal write 'Systemctl start/stop/restart QosiumProbe'

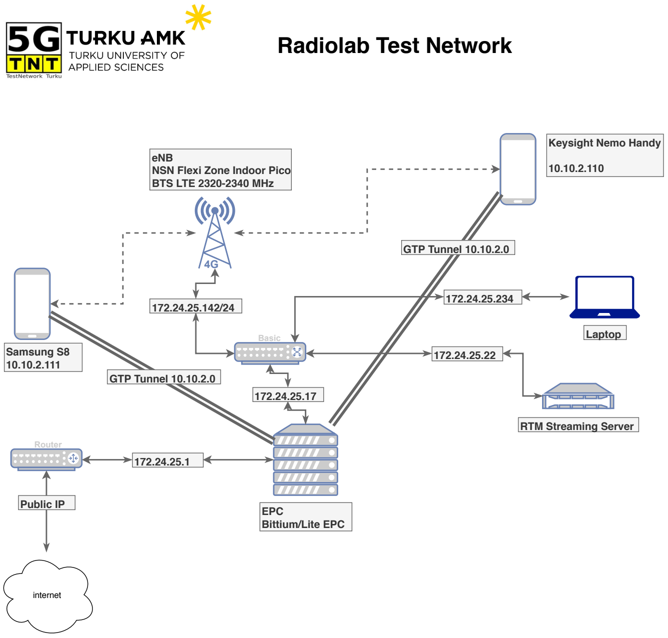


Fig. 1. Network Topology

3) Android: with a rooted phone open Qosium Probe app and click on 'start' if you want to see more details check 'show log'

B. Start Qosium Scope

Scope can be run in Windows and Linux. However, it is recommended to use it on Windows, because we can work with a graphical user interface (GUI). It is very useful, especially when we are checking if the real-time measurements in the graphs make sense.

C. Setting Qosium Scope

1) Connecting Probes: The first step is connecting the probes; doing that, we have to be in the same network; that is Local Area Network (LAN). An easy way to know in advance if we can reach the probes is doing a ping to that device. e.g., from 172.24.25.234 ping to 10.10.2.111. If we receive a response, we can go to Qosium Scope, then in an upper bar select view and then click on 'settings Wizard' there we can choose between single-point measurement or two-point measurement.

- Take note that it is vital to decide which one will be the primary probe and the secondary, check-in Fig. 2 the QoS Measurement Control Protocol (QMCP) streams are not following the same route to the Scope. So if we have a lousy condition network in the smartphone and we choose this one as the primary probe, the traffic load will be significantly higher because we would be sending the application data traffic plus primary and secondary QMCP streams, and it will lead to a connection breaks while measuring.

2) Select interface: If the probes have been connected, then we have to choose what interface we want to capture. Usually, we work with switches, Servers these devices have many interfaces. It could be difficult knowing what the interface where our traffic is flowing, so for that, Wireshark is our ally, because it is advantageous when we do not have a clear idea of what is going on in the network also It will be explained later other scenarios where Wireshark is helpful.

3) Configuring Sender Addresses: Qosium needs to know who is the originating node of the stream we want to measure, so why sometimes we have to specify it in 'sender addresses' in 'manual select' we have to write the IP of the sender if this is not the endpoint or the start point of the traffic like in the Fig. 2 one probe is running in EPC, which is a middle point in the network; that is why we need to tell Qosium what is the IP of the sender for more details check the screenshot next to EPC in Fig. 2.

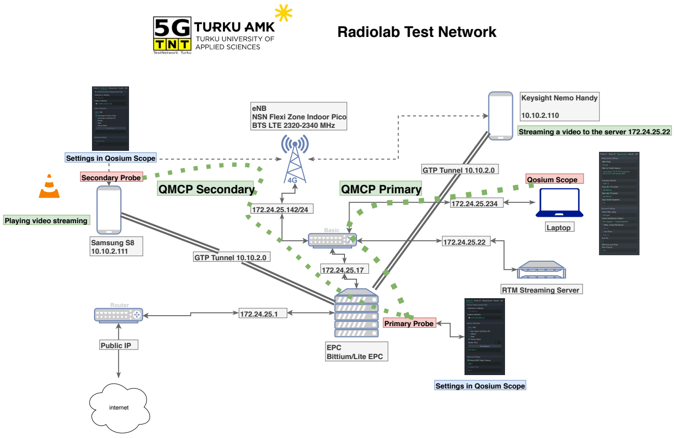
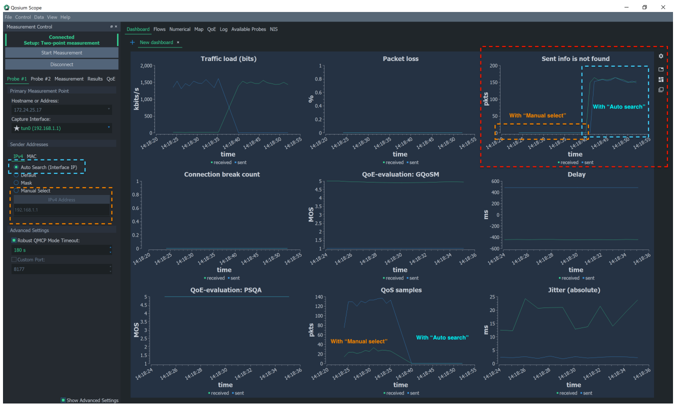


Fig. 2. Topology and settings for measuring video streaming

On the other hand, the phone is an endpoint in the network, so checking the screenshot next to the Samsung S8 we can select 'According to Primary Probe.' It could be hard at the beginning to understand, here in Fig. 3 it is shown the difference between right and wrong setting with Sender Addresses.

Fig 3 Shows a comparison getting the right results and wrong results. It can be appreciated that in "sent info is not found," declares that Qosium does who is sending the information, that is why we have to set in "Sender Addresses" the IP of the sender to get right results.


Qosium Scope

Measurement Control

Connected
Setup: Two-point measurement

Primary Measurement Point
Hostname or Address: 172.24.25.17
Capture Interface: ★ tun0 (192.168.1.1)

Sender Addresses
IPv4 MAC
● Auto Search (Interface IP)
○ Default
○ Mask
○ Manual Select
IPv4 Address
192.168.1.1

Advanced Settings
☑ Robust QMCP Mode Timeout: 180 s
☐ Custom Port: 8177

Fig. 3. Differences between right configuration and wrong configuration

IV. MEASUREMENTS

In the section ' measurement,' the most important parameters are 'Filter and Packet Capture' and 'Packet Identification Method,' in Fig. 2 next to the laptop, there is a screenshot with the measurement settings for that test.

A. Filter and Packet Capture

Here we have to write the IP and host of the Probes in this case 172.24.25.22 (Primary probe) and 10.10.2.111 (Secondary Probe), even though the traffic of QMCP is much smaller than the primary traffic, it can alter the measurements, so we have to specify in the filter 'not port 8177' which is the port QMCP uses.

B. Packet identifcation Method

'IPv4 ID Field' or 'NAT bypasser + Payload based ID ' These two are the most commonly used options for making measurements. it is straightforward to understand when we should use each one, if in the network exists some NAT we have to use NAT bypasser + Payload based ID if not using IPv4 ID Field will be enough, actually I prefer using all the time NAT bypasser + Payload based ID even if there is not any NAT it will work fine.

V. RESULTS

In the tab 'results,' we have to define what type of results we want to get and write into the working directory.

I don't recommend marking get Pcap results, because as I said before it can be problematic when we are working a not very reliable network due to the traffic load in the network, if the link is weak it can lead into connection breaks and Qosium will take longer to show results, so unless it is strictly necessary. It is recommended to work with Average Results, Packet Results, and Flow results for most of the tests will be enough.

VI. MAP VISUALIZATION

Qosium offers another option to visualize results. It is a 'map tab,' there we can use heat-map for visualizing our results, e.g., QoS, delay, Traffic load. Location services are required for that. However, we can attach an indoor plan as an Overlay image in map options and work with the manual location.

A. *Set up*

It is the last step before starting the measurement; in this section is very important to follow the step in order if not could be some issues with the maps.

1) Select the map style.
2) Mark Allow Downloading Map tiles.
3) Clear map-cache.
4) Select location source; once the measurement starts, the probe position should appear on the map.
5) If you want to make an indoor measurement, use Overlay Image, click on Add Image source, and set the coordinates manually.
6) Choose the source that it is wanted to draw on the map.
7) If you want to see real-time measurements on the map, click on Auto-update.
8) Start the measurement.

B. *Overlay Images*

For adding images overly into the map, we have to take into account a couple of things. If you experience some problems to visualize the images. I recommend you to do this:

if the map is partly loaded could some problems, to fix that:

1) Check the formats of images (PNG, JPG, gif)
2) Change the map style
3) clear map cache
4) change again the map style to the original
5) check that 'Allow Downloading Map tiles' marked

Another issue that could occur is that the image is loaded, but you cannot see it because the coordinates are not well configurated, to fix that:

1) Top latitude is greater than bottom latitude
2) Longitude on the left is smaller than longitude on right

C. *Heat map*

In the heat map section, we can find 'Good limit' and 'Bad limit.' e.g., QoE evaluation is easy to know because it has a fixed value between 1-5 so we can set that values before the measurement, but usually, we are not going to know in advance these values. Once the measurement end, we can define the values or click in auto limits and the heat map colors will update instantaneously.

I recommend for indoor measurements 'Draw distance' and 'Opacity' the value of 2 meters in both. For outdoors, these values should be higher around 10 meters. Fig. 4 is an example of QoS heat map indoor measurements.

Fig. 4. QoS measurements in ICT City second floor

VII. EXAMPLE MEASUREMENTS

In this section, it is presented two examples of video stream measurements, measured in the Radiolab Test Network, the topology, and distribution of the probes can be seen in Fig. 2.

A. *One-point measurements*

The measures that Qosium can show are minimal with one-point measurement; it is basically because with only one point the information that Qosium have from the network is very poor, we only can analyze Traffic statistics, due to the information is only remaining to our extreme of the network.

However, for some simple measures might be enough to understand what is going on in the measuring point.

TABLE I
ONE POINT MEASUREMENT TRAFFIC STATICS (SEND AND RECEIVED)

Primary Measurement point: Traffic statistics	
Packet size (bytes)	Number of packets (pkts)
Total packets	Packets dropped (pcap,interface)
Traffic load (bits/s)	Traffic total (bytes)

1) Results: In Fig. 5 it is represented the size of the packets during the video streaming measurement, it is remarkable that packets size in a video steaming is not symmetric. From the server perspective in the downlink packets, size is fixed to 1500 bytes, not compression at all, but then the video steaming is processed in the server and sent to a UE (up-link), here we can appreciate a video compressing in the packet size of up-link.

In Fig. 6 we can appreciate the same pattern due to video compression, in the traffic load received in the server from the terminal that streamed the video, and the traffic load sent to the UE that was visualized the video.

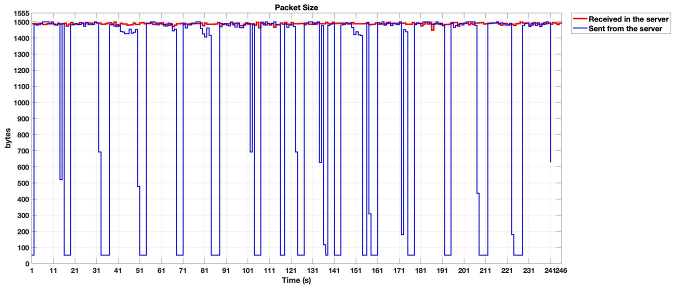


Fig. 5. Packets size from UE to server and from server to UE

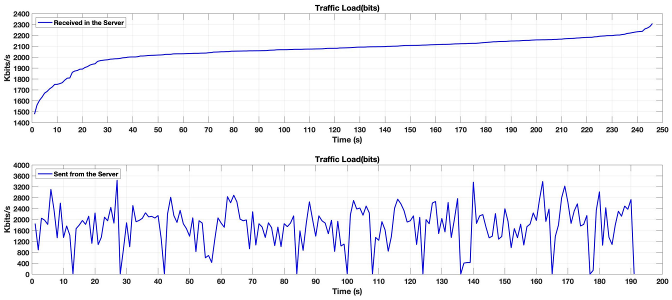


Fig. 6. Traffic load Received in the server and sent to UE

B. Two-points measurements

To perform more advanced measurements. We need to perform two-point measurements. In this case, Qosium offers us more detailed information such as QoS, QoE statistics, and QoS related statistics. See tables: II, III, IV

TABLE II
TWO- POINT MEASUREMENT: QOS STATISTICS

QoS statistics	
Connection break(Count,Duration,length)	Delay
Lost Packets(% , number of packets)	QoS samples
Jitter (Absolute, moving average)	Successfull packets

TABLE III
TWO- POINT MEASUREMENT: QOE STATISTICS

QoE statistics	
QoE-evaluation: GQoSM	QoE-evaluation:PSQA

TABLE IV
TWO- POINT MEASUREMENT: QOS REALTED STATISTICS

QoS related statistics	
Duplicates at the Primary Probe Sent infor is not found	Duplicates at the Secondary Probe sent info is not found total

Of course, in two-point measurement, we can perform one-point measurements; see Table. I. However, on this occasion, we can perform one-point measurements in each probe. This test scenario can be performed opening three Qosium Scopes:

1) One-point measurements in primary probe
2) One-point measurement in secondary probe
3) Two-point measurements.

1) Results: In Fig. 7 it is showed the most representative two-point measurements, such as Delay, QoE, and Traffic load. For example, it can be appreciated after 200 s there is a prominent peak in the delay which it translates in a decrease from 5 to 4.2 in QoE-evaluation.

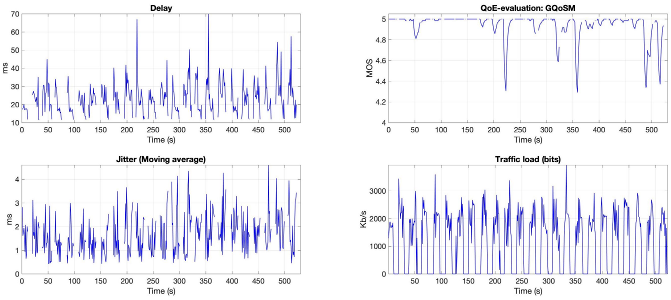


Fig. 7. Two Point video streaming measurements example from Server to UE (uplink)

VIII. CONCLUSION

In this report, I wanted to show a bit of the potential of Qosium software for making measurements in almost everyplace along with any network topology. This tool is crucial for test and analyzing the performance of new technologies like 5G, IoT devices, 360^o videos, VR, and AR applications in real-time.

ACKNOWLEDGMENT

The people who would like to thank for collaborating with me to perform this measurement are Jarmo Prokkola and Marko Palola from Kaitotek. Tibor Lakner and Juha Kalliovaara from Turku University of Applied Sciences.

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How to Perform Measurements with G-NetTrack Pro

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***Abstract*—This document briefly describes the functionalities of the G-NetTrack Pro application. The objective of this document is to explain in detail how the results are shown in the thesis that accompanies this appendix have been obtained.**

***Index Terms*—QoS, G-NetTrack Pro, G-NetLook Web**

I. INTRODUCTION

G-NetTrack Pro is the application for android that has been used to show part of the results of the QoS measurements shown in the Thesis.

It allows us to visualize technical data of the mobile network in use and the neighboring cells. In the map section, it is possible to perform indoor measurements in a manual mode and outdoor measurements in an automatic mode. In the info section, it allows us to see the temporal progress of the received powers as well as the upload and download bitrates.

In this document, we will describe the most important features used to make the measurements of the Thesis, as well as the indications to perform indoor and outdoor measurements.

In section II the most relevant features of the application will be described.

Sections III and IV will explain how to perform indoor and outdoor measurements and the necessary considerations to export and import the results.

Section V will describe one of the best features of this application. That is the possibility to take measurements with multiple devices from a mobile server at the same time.

Finally, in the conclusion section, the advantages and disadvantages that have been appreciated during the use of the application to perform the measurements are presented.

II. SECTION TABS DESCRIPTION

In this section, the most relevant features of each of the section tabs available in the application are described.

A. *Cell Tab*

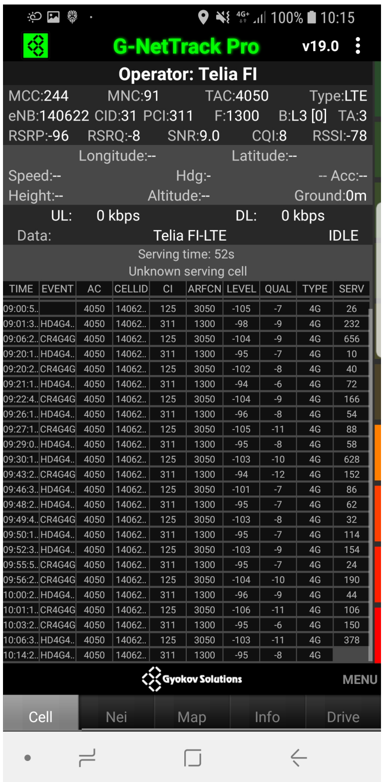
In this section, it is possible to visualize the network's technical information where the terminal is connected in Table I; the most relevant parameters are described.

Besides, it is possible to see in a table all the neighbor cell measurements with their Cell ID, absolute radio-frequency channel number (ARFCN), or technology (3G, 4G, 5G). A screenshot with all the details is shown in Fig 1.

Figure 1 shows the main screen in the app with all the technical data and neighbor Serving cells.

TABLE I
TECHNICAL DATA FROM CELL SECTION IN G-NETTRACK PRO

Mobile Country Code (MCC)	Mobile Network Code (MNC)
Cellular Technology (3G, 4G, 5G)	Carrier ID (CID)
Frecuency (F)	Channel Quality Indicator (CQI)
Reference Signal Receive Power	(RSRP)
Received signal strength indicator	(RSSI)



Operator: Telia FI
MCC:244 MNC:91 TAC:4050 Type:LTE
eNB:140622 CID:31 PCI:311 F:1300 B:L3 [0] TA:3
RSRP:-96 RSRQ:-8 SNR:9.0 CQI:8 RSSI:-78
Longitude:-- Latitude:--
Speed:-- Hdg:- -- Acc:--
Height:-- Altitude:-- Ground:0m
UL: 0 kbps DL: 0 kbps
Data: Telia FI-LTE IDLE
Serving time: 52s
Unknown serving cell

TIME	EVENT	AC	CELLID	CI	ARFCN	LEVEL	QUAL	TYPE	SERV
09:00:5..		4050	14062..	125	3050	-105	-7	4G	26
09:01:3..	HD4G4..	4050	14062..	311	1300	-98	-9	4G	232
09:06:2..	CR4G4G	4050	14062..	125	3050	-104	-9	4G	656
09:20:1..	HD4G4..	4050	14062..	311	1300	-95	-7	4G	10
09:20:2..	CR4G4G	4050	14062..	125	3050	-102	-8	4G	40
09:21:1..	HD4G4..	4050	14062..	311	1300	-94	-6	4G	72
09:22:4..	CR4G4G	4050	14062..	125	3050	-104	-9	4G	166
09:26:1..	HD4G4..	4050	14062..	311	1300	-96	-8	4G	54
09:27:1..	CR4G4G	4050	14062..	125	3050	-105	-11	4G	88
09:29:0..	HD4G4..	4050	14062..	311	1300	-95	-8	4G	58
09:30:1..	HD4G4..	4050	14062..	125	3050	-103	-10	4G	628
09:43:2..	CR4G4G	4050	14062..	311	1300	-94	-12	4G	152
09:46:3..	HD4G4..	4050	14062..	125	3050	-101	-7	4G	86
09:48:2..	HD4G4..	4050	14062..	311	1300	-95	-7	4G	62
09:49:4..	CR4G4G	4050	14062..	125	3050	-103	-8	4G	32
09:50:1..	HD4G4..	4050	14062..	311	1300	-95	-7	4G	114
09:52:3..	HD4G4..	4050	14062..	125	3050	-103	-9	4G	154
09:55:5..	CR4G4G	4050	14062..	311	1300	-95	-7	4G	24
09:56:2..	CR4G4G	4050	14062..	125	3050	-104	-10	4G	190
10:00:2..	HD4G4..	4050	14062..	311	1300	-96	-9	4G	44
10:01:1..	CR4G4G	4050	14062..	125	3050	-106	-11	4G	106
10:03:2..	CR4G4G	4050	14062..	311	1300	-95	-6	4G	150
10:06:3..	HD4G4..	4050	14062..	125	3050	-103	-11	4G	378
10:14:2..	HD4G4..	4050	14062..	311	1300	-95	-8	4G	

Fig. 1. Cell section Screenshot from G-NetTrack Pro

B. *Nei Tab*

This particular section has not been used to perform the measurements, as it is dedicated to giving information about the neighboring cells, and in the measurements taken, only one cell was active.

In this section, we can find information about the neighboring cells. The information is displayed in two tables.

The first table shows information (Cell id and signal level) about the cell to which the UE is connected.

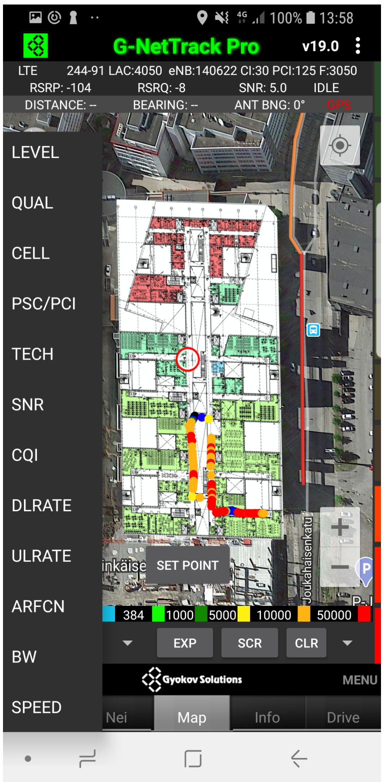
The second table shows the information (cell id and signal levels) of the neighboring cells.

The phone model may limit this section since not all models have all the features available, but more information about the compatibility of each model can be found in [1].

More information is available in the manual [2].

C. Map Tab

This section is perhaps the most interesting of the application. It allows us to visualize the measurements being taken both indoors (manually mode) and outdoors (automatic mode). It is possible to measure QoS metrics and also it is possible to display on the map information like the cell ID or Physical Cell ID (PCI in 4G) described in the table II. Besides, figure 2 shows a test measuring the DL Rate on the first floor of the ICT-City building.



LTE 244-91 LAC:4050 eNB:140622 CI:30 PCI:125 F:3050
RSRP: -104 RSRQ: -8 SNR: 5.0 IDLE
DISTANCE: -- BEARING: -- ANT BNG: 0° GPS

Fig. 2. Indoor measurements map tab screenshot from G-NetTrack Pro

TABLE II
METRICS AVAILABLE FOR PERFORMING MEASUREMENTS IN G-NETTRACK PRO

LEVEL (Signal Level in dBm)	Qual (RSRP on 4G in dBm)
SNR only for 4G in db	CQI (1-15) only 4G
DL & UL Bitrates in Kbit/s	Bandwidth (BW) in MHz
TECH (cellular Technology 2G,3G,4G,5G)	SPEED in Kmph

D. Info Tab

This section shows much information in real-time such as Reference Signal Received Quality (RSRQ), Signal to noise ratio (SNR), Bitrates DL UL, among others. To see all the data visit the manual in section 2.4 Info [2].

Figure 3 shows the metrics in real-time measured from G-NetTrack Pro.

RSRQ are key measures of signal level and quality in LTE networks. RSRQ is a complement when Reference Signals Received Power (RSRP) is not sufficient to decide on handover or cell reselection procedures.

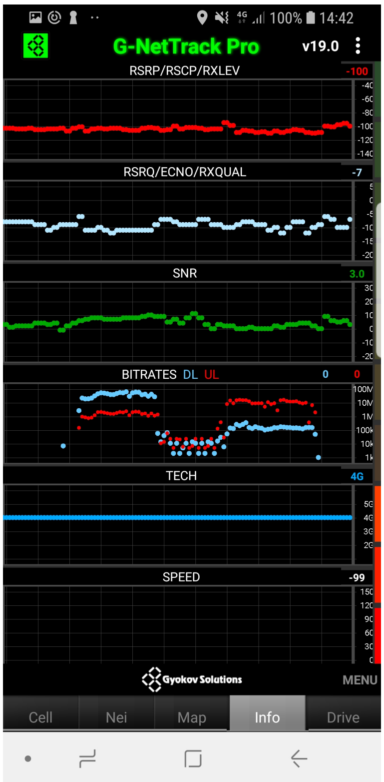


Fig. 3. Real-Time metrics in info Tab in G-NetTrack Pro

The option that is worth describing in this document is the possibility to convert the phone into a server or client using G-NetTrack Pro. The server mobile controls the client mobile when taking measurements to start the measurements simultaneously and take measurements in indoor at the same time in up to 8 devices at the same time. In the fifth section it will be explained how to connect the server with the clients via Bluetooth.

Figure 4 shows the clients connected to the server using G-NetTrack Pro while performing VoIP measurement for the Thesis.

III. MEASURING WITH G-NETTRACK PRO

First of all, it is necessary to take into consideration where the measurements will be made indoors or outdoors since the procedure changes a little.

First of all, the steps for indoor QoS measurements in the ICT-City building for VoIP and video-streaming QoS measurements will be detailed.

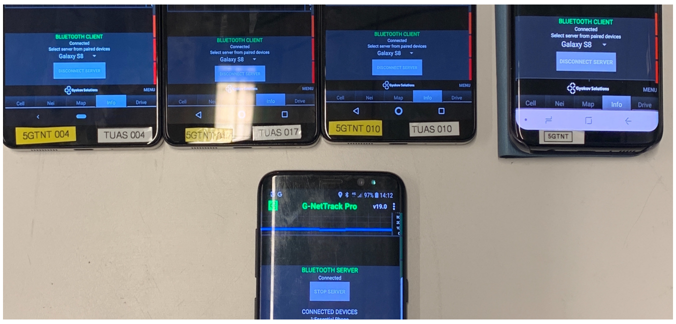


Fig. 4. Connection between Server and G-NetTrack Pro clients

Indoors Measurements

In order to take measurements indoors, the indoor mode must first be activated so that measurements can be taken manually.

1) go to the top right and look for three vertical points.
2) Click on Settings
3) go to indoor and click on Indoor Mode.

Now we have activated the indoor mode to take measurements. Something worth mentioning is that in the indoor setting, we can also select ”Auto indoor mode,” which is useful when taking measurements outdoors, but for a short period, the GPS signal gets lost. For example, in a tunnel where the GPS signal will be lost automatically, it will activate the indoor mode temporarily to take measurements inside the tunnel.

The next step we would be interested in would be to add an interior plan on the available map. Well, this is perhaps the most challenging part as the way to do it is quite impractical. Although G-NetTrack Pro is one of the best applications that have been tested to carry out interior QoS measurements, its major disadvantage is that there is no easy way to import an interior plan. However, by following the following trick, it can be done.

The trick that is going to be explained is only necessary if we do not have the interior plan oriented to the north, which will happen most of the times, therefore there is no more alternative than to do the following steps to get the final result that is shown in the Figure 5.

Figure 6 shows the ICT-CITY building in google maps with the map facing north. This is the key point we have to get the floor plan in the same position as the building on the map facing to the north.

1) The first step is to go to Google Maps and locate the building where the indoor plan will be added.
2) We take a screenshot of the building with the map facing north.
3) Using a photo editing program, we have to overlay the photo of the interior map with the photo of the building taken with the map facing north.

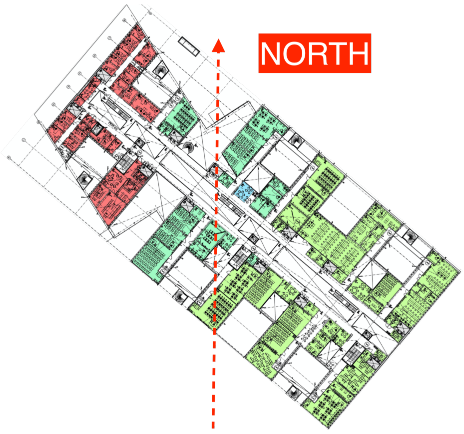


Fig. 5. Interior map with Google Maps bird’s eye view facing north.

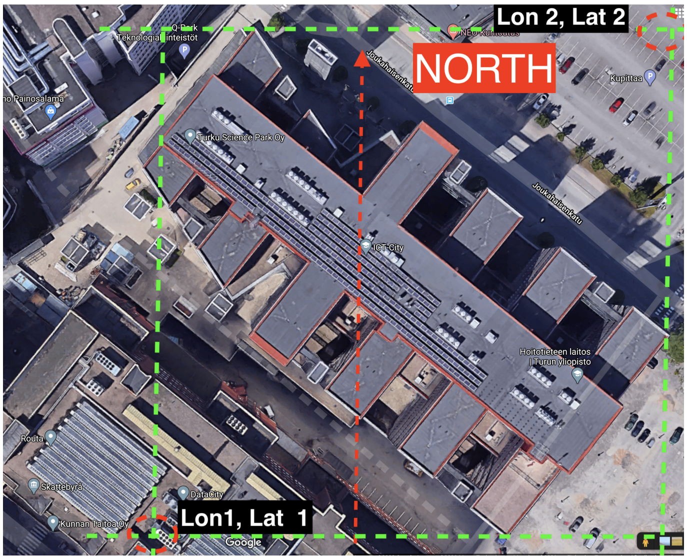


Fig. 6. ICT-City from Google Maps bird’s eye view facing north

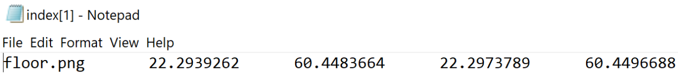
4) Once the floor plan is perfectly placed, the background of the image must be removed and cut out like the green square of the Figure 6.
5) The result should look like the one in Figure 5. The floor plan has to be exported in PNG format.
6) Finally, go back to google maps and take the coordinates in the right place. See figure 6. The coordinates of the lower-left corner must be taken as longitude 1 and latitude 1 and as longitude 2 and latitude 2 the coordinates of the upper right corner with the map oriented to the north.

A. *Import Floor plan to G-NetTrack Pro*

In order to import the plan, connect the mobile phone to a computer, and follow the steps below.

1) Connect the phone and look for the folder ”G-NetTrack_Pro_Logs”

2) If a folder called ”floorplan” does not exist, create it.
3) Creates a .txt file with the name ”index”, i.e. index.txt.
4) Enter the name of the plane .png with tab spacing enter the first longitude and first latitude the same for the second longitude, and latitude. See figure 7 to understand it better.



```
floor.png	22.2939262	60.4483664	22.2973789	60.4496688
```

Fig. 7. Index.txt with the tab spacing and the coordinates needed

1) Once we have both the index.txt file and floorplan.png, copy these two files into the floorplan folder.
2) Now in G-NetTrack Pro, click on the three points and select ”Load Floorplan. A message ” 1 floorplan added” should be displayed, and if everything is OK, it should appear in the desired position like in Figure 2.

B. Start measuring

Once everything is in place, measurements can be taken. We have to go to the three points and click on the ”start log.”

The G-NetTrack Pro logo will change from green to red to indicate that the measurements are being recorded.

Once the measurements have been taken, they will be saved in the ”G-NetTrackProLogs” folder with the name of the operator on the day and time.

In the Thesis, G-NetTrack Pro was used to perform measurements on VoIP calls and video-streaming. On a 4G network, where the application is fully supported. G-NetTrack Pro offers information on 5G networks, but it is still not fully supported. Nevertheless, this is not a problem that will be solved through future software updates.

Outdoor Measurements

To perform outdoor measurements, the procedure is quite similar to the above described.

First of all, the indoor mode has to be deactivated, but if during the trip, it is expected that the GPS signal might be lost, it is recommended to have the indoor auto mode activated.

Because the outdoor measurements are taken automatically once we start logging, we can customize both the measuring interval in the distance traveled and in time if we do not move.

By default, the time interval between measurements if there is no movement is defined at 600 s, but it can be changed. To do this, go to Settings and look for the option ”LOG PARAMETERS” and ” Time interval S.”

To modify the distance interval between measurements within ”LOG PARAMETERS,” look for ”Distance interval m” by default is 10 m.

These modifications are customizable according to the needs of the measurements to be performed. Therefore this level of customization in the taking of measurements is an advantage.

IV. EXPORTING RESULTS

To export the results found in the corresponding folder in ”G-NetTrack_Pro_Logs”, copy it, and save it where convenient.

In the folder, there are many files with different extensions. The relevant ones are the .kml files that contain the GPS information and the file that we are going to use to visualize the measurements taken. This file is a .txt file with the same name as the folder that contains it.

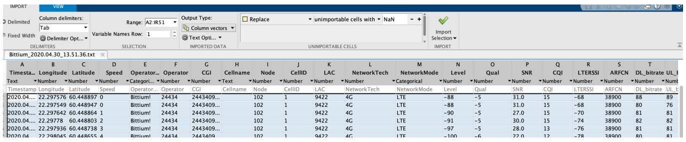
*1) **Visualizing Results**:* To visualize the results shown in the thesis. Two programs have been used.

On the one hand, MATLAB to graph the results and, on the other hand, G-NetLook Web to see the measurements on a map.

*2) **MATLAB**:* To graph, the results the time vector and a result vector are needed. To export the results as vectors in MATLAB, we need to import the data.

To import the data, we go to the ”Import Data” option in MATLAB. Please select the file with the same name as the folder containing it, and the extension is .txt. For example, ”Bittium_2020.04.30_13.51.36.txt”.

Figure 8 shows an example of importing the data as vectors. It is essential to define in the upper bar where the data is and where the data names are.



Column delimiters: Tab
Range: A2:IR51
Variable Names Row: 1
Output Type: Column vectors
Replace unimportable cells with NaN

Bittium_2020.04.30_13.51.36.txt

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
Timesta...	Longitude	Latitude	Speed	Operator...	Operator	CGI	Cellname	Node	CellID	LAC	NetworkTech	NetworkMode	Level	Qual	SNR	CQI	LTERSSI	ARFCN	DL_bitrate	UL_
Text	Number	Number	Number	Categori...	Number	Number	Text	Number	Number	Number	Number	Categorical	Number	Number	Number	Number	Number	Number	Number	Numb
Timestamp	Longitude	Latitude	Speed	Operator...	Operator	CGI	Cellname	Node	CellID	LAC	NetworkTech	NetworkMode	Level	Qual	SNR	CQI	LTERSSI	ARFCN	DL_bitrate	UL_b
2020.04....	22.297576	60.448897	0	Bittium!	24434	2443409...		102	1	9422	4G	LTE	-88	-5	31.0	15	-68	38900	88	89
2020.04....	22.297549	60.448947	0	Bittium!	24434	2443409...		102	1	9422	4G	LTE	-88	-5	31.0	15	-68	38900	80	76
2020.04....	22.297642	60.448864	1	Bittium!	24434	2443409...		102	1	9422	4G	LTE	-90	-5	27.0	15	-70	38900	81	81
2020.04....	22.29778	60.448803	2	Bittium!	24434	2443409...		102	1	9422	4G	LTE	-91	-5	30.0	15	-74	38900	82	82
2020.04....	22.297936	60.448738	3	Bittium!	24434	2443409...		102	1	9422	4G	LTE	-97	-5	28.0	13	-76	38900	81	81
2020.04	22.298045	60.448655	4	Bittium!	24434	2443409		102	1	9422	4G	LTE	-100	-6	22.0	12	-78	38900	80	81

Fig. 8. Importing data from G-NetTrack Pro to MATLAB

*3) **G-NetLook Web**:* Gyokov Solutions is the company that created G-NetTrack Pro. G-NetLook Web is the visualization of the same company that export and visualize the results from our computer.

It offers basic functions such as drawing the colored points according to the measurements on a map. However, and as the main disadvantage, it does not allow us to add a plan for the interior measurements.

To be able to visualize later the measurements taken indoors with a map, it is believed that the application ”G-NetView Pro” is needed but it cannot be confirmed since I have not been able to test it and in the free version it does not work, but the procedure to add the map should be the same as the one described above.

To be able to import the data, it is necessary to have the .txt file with the same name as the folder that contains it, for example, ”Bittium_2020.04.30_13.51.36.txt”.

Accessing G-NetLook Web see [3].

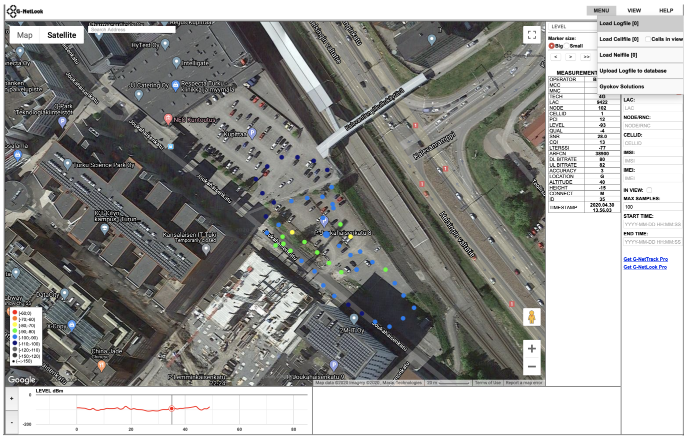
In the upper part selecting ”MENU” and ”Load LogFile[0],” we load the .txt file.

Automatically the program will show us the results in the location where they were all.

We can visualize all the parameters described in the first section.

In addition, the visualization uses Google Maps and allows us to view the data in the ”Street View” mode. This way of showing the results can be very interesting.

Figure 9 shows a screenshot where the option to upload the data to the G-NetLook Web is shown.



MEASUREMENT

OPERATOR	B
MCC	
MNC	
TECH	4G
LAC	9422
NODE	102
CELLID	1
PCI	12
LEVEL	-93
QUAL	-4
SNR	28.0
CQI	13
LTERSSI	-77
ARFCN	38900
DL BITRATE	80
UL BITRATE	82
ACCURACY	3
LOCATION	G
ALTITUDE	40
HEIGHT	-15
CONNECT	M
ID	35
TIMESTAMP	2020.04.30 13.56.03

MAX SAMPLES: 100

Fig. 9. G-NetLook Web capture

V. REMOTE CONTROL

The possibility of being able to perform measurements with multiple devices simultaneously is a great advantage for certain measurements.

For example, during the measurements with the VoIP group call, it was possible to take measurements of all devices in the call to see if there were differences in the measurements.

The figure 10 shows an example.

The terminal in the center is the server, and the terminals around it are the clients.

The control is done by Bluetooth and allows us to start and stop the data recording. Besides being able to perform indoor measurements at the same time.

To configure the control mode via Bluetooth, the following steps must be followed.

1) In Settings search for ”BLUETOOTH CONTROL,” within this option, select Bluetooth client or server.
2) restart the application.
3) Go to the phone settings and activate Bluetooth on all devices.

Fig. 10. Devices taking simultaneous measurements with G-NetTrack Pro

4) Pair all devices with the mobile server by selecting the mobile that will act as the server in the list of Bluetooth devices.
5) Return to the application and in the mobile phone that will act as a server, in info tab scrolling down and click on activate the option ”START SERVER.”
6) in the clients, it is necessary to go to the info tab, scroll down, and activate ”CONNECT TO SERVER.”

If everything is correct, it should appear with green letters ”Bluetooth server” and ”Bluetooth client” in the respective terminals, as in figure 4.

Once we have all the devices paired from the server, we can start recording the measurements and start on all devices simultaneously.

Once we have finished taking measures to export the data, we must do it one by one.

VI. CONCLUSION

The steps necessary to perform QoS measurements with the G-NetTrack Pro application have been described in this document.

Its advantages include its fast set-up and handling and the multiple customizations that are available to take measurements, such as changing the time interval or the distance traveled between measurements. Measurements in indoor mode are drawn where they need to be drawn since, in other applications, they are not as accurate as G-NetTrack pro. As a unique advantage over other applications to measure QoS, it stands out the possibility of taking measurements simultaneously with several devices paired by Bluetooth. This feature can be very useful to compare measured results under the same conditions.

As for disadvantages that have been observed during the performing of these measures, we highlight that although the application is available for all Android devices with a recent software version, not all models support the same features. Besides, the use of plans in indoor mode is impractical since it requires much previous work to adapt to the plans. It would be all easier if the application allowed to move the plane with the fingers.

The results achieved for the realization of the thesis have been satisfying, however for professional or industrial use, the application is limited since it can only be used in android mobile devices, which dramatically limits its versatility. Nevertheless, without a doubt, this tool is very useful to obtain quick and preliminary results.

REFERENCES

[1] G-NetTrack phone measurement capabilities. Available at: http://www.gyokovsolutions.com/survey/surveyresults.php. Accessed May, 2020.

[2] Gyokov Solutions. G-NetTrack Pro Manual. Available at: https://www.gyokovsolutions.com/manuals/gnettrackpro_manual.php. Accessed May, 2020.

[3] G-NetLook viewer. Available at: https://www.gyokovsolutions.com/G-NetLook/. Accessed May, 2020.

[4] RSRP and RSRQ. Available at: https://wiki.teltonika-networks.com/view/RSRP_and_RSRQ.