MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE NATIONAL AVIATION UNIVERSITY

FACULTY OF AERONAVIGATIONS, ELECTRONICS AND TELECOMMUNICATIONS

DEPARTMENT OF TELECOMMUNICATION AND RADIO ENGINEERING SYSTEMS

ADMIT TO DEFENCE
Head of the Department

____________ Victor HNATIUK
“_____” ______________2023 р.

QUALIFICATION WORK

(EXPLANATORY NOTE)

MASTER'S DEGREE GRADUATE

Topic: «Analysis of Quality Control and Management in Mobile Networks Considering the Requirements of 4G and 5G Technologies»

Performer: ____________________ Anzhela LOMACHEVSKA
(signature)

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Consultant in the «Occupational Safety» Section: __________ Batyr KHALMURADOV
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Kyiv 2023

NATIONAL AVIATION UNIVERSITY

Faculty of aeronautics, electronics and telecommunications
Department of telecommunications and radioelectronic systems
Specialty 172 «Telecommunications and radio engineering»
Educational professional program «Telecommunication systems and networks»

ADMIT TO DEFENCE
Head of the Department

________ Viktor HNATIUK
"_____"_____________2023

TASK
for the performance of qualification work

Lomachevska Anzhela
(last name, first name, patronymic of the graduate in the genitive case)

1. Topic of thesis (project): " Analysis of Quality Control and Management in Mobile Networks Considering the Requirements of 4G and 5G Technologies "

approved by the rector's order dated September 8, 2023 No. 1965/ art

2. The term of the work: from 02.10.2023 to 31.12.2023.

3. Initial data for work: Mobile network technologies, 4G and 5G transition, quality control challenges

4. Contents of the explanatory note: Quality of service in mobile networks, Requirements and characteristics of 4G and 5G technologies, Data Compression Techniques for Efficient Mobile Network Monitoring

5. List of mandatory graphic (illustrative) material: The architectural framework of the (QoM) concept, General scheme of the experiment, Compression achieved and Mean Square Error concerning different information loss limits ($k \times \sigma$) used for the compression

6. Calendar plan-schedule

№ cf.	Tasks.	Term. execution	Mark of completion
1	Develop a detailed content of the qualification work sections	02.10.2023-04.10.2023	Done
2	Introduction	05.10.2023-08.10.2023	Done
3	Quality of service in mobile networks	09.10.2023-22.10.2023	Done
4	Requirements and characteristics of 4G and 5G technologies	23.10.2023-05.11.2023	Done
5	Data Compression Techniques for Efficient Mobile Network Monitoring	06.11.2023-30.11.2023	Done
	Labour protection	07.12.2023-17.12.2023	Done
7	Environmental protection	21.11.2022-30.11.2022	Done
8	Elimination of deficiencies and defence of qualification work	21.11.2022-30.11.2022	21.11.2022-30.11.2022

7. Consultants from separate sections

Chapter	Consultant (position, Full Name)	Date, signature	
		Issued the task	Task accepted
Occupational Safety	Ph.D. in Med., Professor Batyr KHALMURADOV		
Environmental Protection	Ph.D. in Biol., Associate Professor Andrian IAVNIUK		

8. Release date of the task: September “29", 2023

Supervisor of Qualification Work______________________ Oleksandr PUZYRENKO
(signature of the supervisor) (full name)

The task has been taken on for execution_________________ Anzhela LOMACHEVSKA
(graduate signature) (full name)

ABSTRACT

The qualification work "Analysis of Quality Control and Management in Mobile Networks Considering the Requirements of 4G and 5G Technologies" 130 contains pages, 34 figures, 10 tables, 36 sources.

MOBILE NETWORKS, QUALITY CONTROL, TELECOMMUNICATION, 4G, 5G.

Object of study – modern mobile networks undergoing the transition from 4G to 5G technology. The deployment and integration process of these advanced technologies give rise to challenging situations, becoming the focus of the investigation.

Subject of study – the mechanisms of control and quality management in mobile networks, taking into account the requirements of 4G and 5G technologies. Within the scope of the object, which constitutes modern mobile networks, a specific portion is identified as the subject of investigation-namely, the mechanisms of control and management that undergo thorough analysis and design.

The purpose of the thesis is to investigate and explore the mechanisms of quality control and management in mobile networks during the transition from 4G to 5G technology, focusing on technical aspects, the requirements of new technologies, and the identification of potential issues. Develop a software product using the Python environment to enhance user awareness of mobile network parameters, taking into account the requirements and innovations of 4G and 5G technologies.

Research methods:

1. Technical Aspects Analysis.

2. Evaluation of 4G and 5G Technology Requirements.

3. Software Product Development.

The thesis materials are recommended to be used in conducting scientific research and the educational process.

CONTENTS

LIST OF SYMBOLS

AI – Artificial Intelligence.

CoMP – Coordinated Multi-Point.

CoS – Class of Service.

DF – Data Fetcher.

DFs – Data Flows.

DH – Data Hub.

DiffServ – Differentiated Services.

DS – Data Switch.

eMBB – Enhanced Mobile Broadband.

eMBMS – Multimedia Broadcast Multicast Service.

EMC – Electromagnetic Compatibility.

EPS – Evolved Packet System.

E-UTRA – Evolved Universal Terrestrial Radio Access.

FD – Full-Dimension.

GBR – Guaranteed Bit Rate.

gNBs – Next-Generation NodeB.

HSPA – High-Speed Packet Access.

IMT – International Mobile Telecommunications.

IntServ – Integrated Services.

IoT – Internet of Things.

ISO – International Organization for Standardization.

ITU – International Telecommunication Union.

KPI – Key Performance Indicator.

KPIs – Key Performance Indicators.

LTE – Long Term Evolution.

MEC – Multi-Access Edge Computing.

MFBR – Maximum Flow Bit Rate.

ML – Machine Learning.

mMTC – Large Machine-Type Communications.

M-Plane – Management Plane.

MPLS – Multiprotocol Label Switching.

MPS – Multi-Media Priority Services.

mPWCA – Modified Online Piecewise-Constant Approximation.

MTC – Machine Type Communication.

NEs – Network Elements.

NMS – Network Management System.

Non-GBR – Non-Guaranteed Bit Rate.

NP – Network Performance.

NR – New Radio.

OFDMA – Orthogonal Frequency Division Multiple Access.

PC – Personal computer.

PDB – Packet Delay Budget.

PELR – Packet Error Loss Rate.

Pub-Sub – Publish-Subscribe.

PWCA – Piecewise-Constant Approximation.

QCI – Quality of Service Class Identifier.

QoM – Quality of Management.

QoMDB – QoM Database.

QoS – Quality of Service.

RAM – Random Access Memory.

RITs – Radio Interface Technologies.

RNC – Radio Network Controller.

RRM – Radio Resource Management.

SC-FDMA – Single Carrier-Frequency Division Multiple Access.

SDF – Service Data Flow.

SD-WAN – Software-Defined WAN.

SRITs – Specialized Radio Interface Technologies.

UE – User Equipment.

UMTS – Universal Mobile Telecommunication System.

URLLC – Ultra-Reliable and Low Latency Communications.

URLLC – Ultra-Reliable and Low-Latency Communication.

UTRA – Universal Terrestrial Radio Access.

UTRAN – Universal Terrestrial Radio Access Network.

V2X – Vehicle-to-Everything.

INTRODUCTION

Relevance of the topic. In the modern world, where mobile technologies become an integral part of our daily lives, the rapid development of 4G and 5G technologies poses important problems and challenges for mobile networks. The speed of transition from the previous generation to the latest, as well as the unstoppable expansion of service capabilities, make issues of control and quality management so relevant that they become key success factors for mobile network operators.

The technological shift from 4G to 5G sets new standards for data transfer speed, information processing, and device interaction. User expectations for stable and high-quality mobile communication have never been higher. In this context, ensuring effective quality control becomes strategically important for operators to meet the demands of the modern user.

The competitiveness of mobile network operators is determined not only by data transfer speed but also by the ability to effectively manage and control service quality. Operators who can adapt their networks to new requirements and technical transition challenges will have a significant advantage in the competitive environment.

The emergence of new services, such as augmented reality, the Internet of Things, and other innovative solutions, increases the diversity of network requirements. Identifying, analyzing, and solving quality control issues for different types of services become crucial components to ensure the successful implementation and functioning of cutting-edge technologies.

Considering the challenges mentioned above, the importance of our research becomes evident. Taking into account the requirements and innovations of 4G and 5G technologies, we aim to create effective mechanisms for quality control and management in mobile networks. Our approach involves a thorough analysis of technical aspects, evaluation of requirements, identification of possible issues, and the development of software aimed at improving user operational awareness. Such an approach is key to the success of modern mobile networks and forms the basis of our scientific research.

Connection of work with scientific programs, plans, themes. Scientific articles and research were used.

The purpose and objectives of the study.

Objective of the work:

To investigate and explore the mechanisms of quality control and management in mobile networks during the transition from 4G to 5G technology, focusing on technical aspects, the requirements of new technologies, and the identification of potential issues. Develop a software product using the Python environment to enhance user awareness of mobile network parameters, taking into account the requirements and innovations of 4G and 5G technologies.

To achieve the set goal, the following scientific tasks are addressed:

1. Technical Aspect: Conduct a thorough analysis of the technical aspects of quality control and management, considering the innovations introduced by 4G and 5G.

2. Requirements Evaluation: Study the requirements imposed by 4G and 5G technologies on quality control, with a particular emphasis on their unique capabilities.

3. Software Product Development: Develop a software product using the Python environment to improve user awareness of mobile network parameters, addressing the requirements and innovations of 4G and 5G technologies.

The object of the study – modern mobile networks undergoing the transition from 4G to 5G technology. The deployment and integration process of these advanced technologies give rise to challenging situations, becoming the focus of the investigation.

The subject of research – the mechanisms of control and quality management in mobile networks, taking into account the requirements of 4G and 5G technologies. Within the scope of the object, which constitutes modern mobile networks, a specific portion is identified as the subject of investigation-namely, the mechanisms of control and management that undergo thorough analysis and design.

Research of methods:

1. Technical Aspects Analysis: A detailed examination of the technical aspects of quality control and management mechanisms in mobile networks, including their characteristics and capabilities during the transition from 4G to 5G.

2. Evaluation of 4G and 5G Technology Requirements: Analysis of the requirements imposed by 4G and 5G technologies on quality control mechanisms, considering their unique capabilities and features.

3. Software Product Development: Development of a software product using the Python environment to enhance user awareness of mobile network parameters, focusing on improving operational information delivery.

Scientific novelty and practical significance of the obtained results.

Scientific novelty of the obtained results:

1. A comprehensive analysis of the impact of 4G and 5G technologies on quality control processes in mobile networks has been conducted, taking into account the specific requirements.

2. The proposal to use chatbots on Telegram as a tool for real-time informing users about mobile network parameters has been introduced. Algorithms for data analysis and the generation of personalized recommendations have been developed.

Practical significance of the obtained results:

1. A detailed analysis of service quality parameter control systems in mobile networks has been conducted, considering the requirements of 4G and 5G technologies and identifying service quality issues.

2. The developed chatbot allows for prompt user notification about the state of mobile networks and provides personalized recommendations for choosing an operator.

CHAPTER 1

QUALITY OF SERVICE IN MOBILE NETWORKS

1.1. Overview of Existing Approaches to Quality Control and Management in Mobile Networks

The effective and dependable operation of contemporary communication systems depends on quality control and management, or QoS, in mobile networks. Let's emphasize some important details on Figure 1.1. that highlight how important this control is.

Fig. 1.1. The importance of Quality Control and Management in Mobile Networks

Ensuring Service Reliability

For mobile networks to remain dependable and uninterrupted, high-quality communication is essential. Consumers anticipate a reliable connection for data sharing, video conferences, and phone conversations, poor quality might result in discontent and lost business.

Supporting Diverse Services

Virtual reality, the IoT, and other cutting-edge apps are just a few of the services that mobile networks are now able to offer thanks to the introduction of faster and more productive technologies like 4G and 5G. The effective operation of these many services depends on QoS.

Effective Resource Utilization

With the growing need for dependable and quick connections, quality management helps mobile networks make the most of their limited resources. Sustaining high performance is made possible by the efficient use of bandwidth and other resources.

Ensuring Real-Time Quality

Low latency and packet loss are essential for some applications, such as video conferencing and audio communication. Real-time quality is guaranteed by QoS, and this is essential for satisfying user demands.

Supporting Technology Expansion

Since mobile technologies are developing so quickly, proper QoS is necessary for the integration and deployment of new technologies. As we go from 4G to 5G and beyond, effective quality control becomes strategically critical.

Protection Against Losses and Damages

When data is being transmitted via a network, packet loss, delays, and other irregularities can be avoided with the aid of quality of service. Ensuring the confidentiality and integrity of data is crucial.

Increasing User Satisfaction

providing good customer service influences the loyalty and general satisfaction of users using mobile communication.

Thus, it is determined that quality management and control in mobile networks are essential components for guaranteeing efficient and superior service delivery, as well as for the industry's expansion and the successful adoption of new technologies [1].

Optimizing performance, user happiness, and the overall effectiveness of the network environment are all dependent on the effective application of quality control and management procedures in mobile networks. Figure 1.2. displays the salient features of this function.

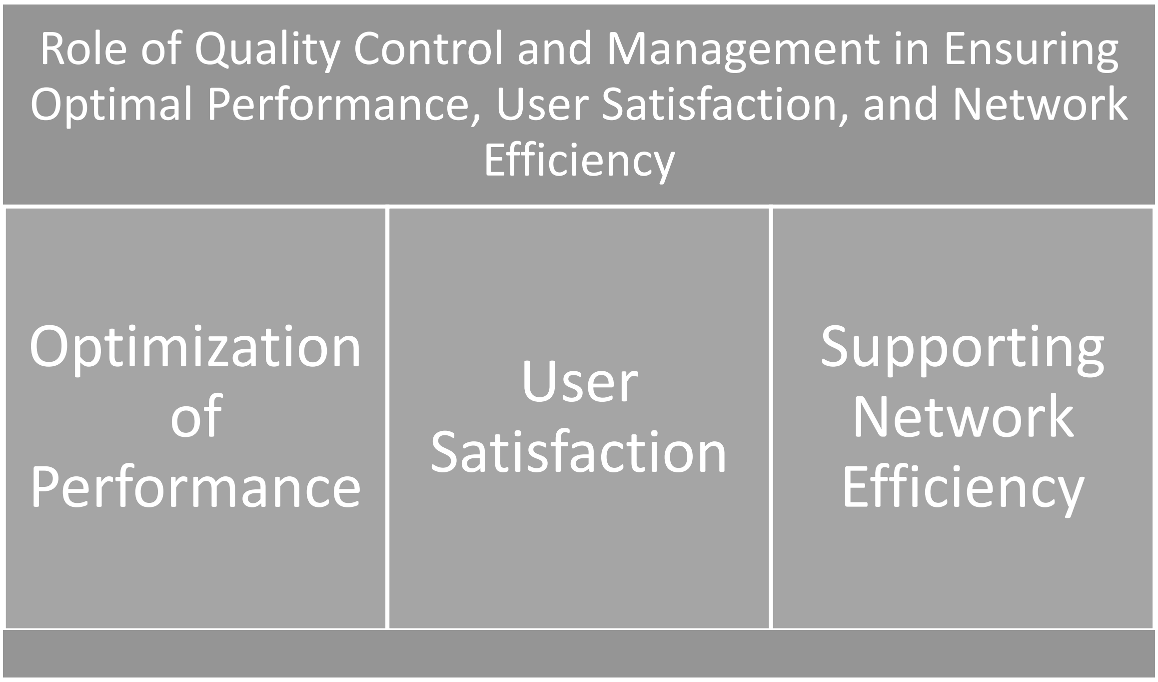


Fig. 1.2. Role of Quality Control and Management

Optimization of Performance

The effective use of network resources is made possible by quality control, which improves overall performance. Maintaining the highest possible standard of service quality helps the mobile network operate better and make the most use of its resources.

User Satisfaction

End users may be assured of the network's stability and dependability through efficient quality management. By offering top-notch services, the mobile network attracts more consumers and encourages total happiness and loyalty.

Supporting Network Efficiency

In order to avoid overloads and guarantee the steady operation of network components, quality control and management are helpful. This is essential to guaranteeing the mobile infrastructure runs efficiently and continuously.

The main objective of these procedures is to provide excellent mobile communication that meets the demands of contemporary users, supporting the long-term growth and profitability of the mobile network.

To improve the effectiveness of M-Plane data management in mobile networks run by network operators, the QoM is a strategic solution. To improve data volume by the removal of duplicate, repeated, and less informative material, the QoM solution uses a set of classes during the data transmission process. Taking into account the required data quality and the criticality of devices and services, these QoM classes are essential in differentiating data collection, transport, and storage across various NEs and network services.

Setting priorities NEs and services that demand the most attention for data gathering and monitoring determines which QoM classes they are allocated to. The highest QoM class is allocated to critical parts and services, guaranteeing thorough data gathering with no information loss. On the other hand, non-essential components and services are categorized under a lesser quality of maintenance class, which suggests that larger data sections with comparatively less information are not gathered.

Through a few components, the QoM system unifies these classes for data reduction and specialized monitoring. These components can be deployed within cellular networks in either mobile edge cloud or core cloud settings, depending on their tasks and requirements for processing resources.

The Pub-Sub paradigm serves as the foundation for the QoM and optimizes data collecting in two important ways. First, by using a subscription pattern, it reduces request interactions from the data consumer (such as the NMS Application). This method involves a single subscription from the customer, and depending on the subscription type, data is published either routinely or intermittently by the data provider. This removes the requirement for repetitive data searches, which are present in systems that rely on polling. Second, the QoM solution effectively speeds the data gathering process in situations where several customers exhibit interest in the same data stream, as opposed to repeating the procedure for each consumer.

The term QoS describes a network's ability to offer various NP levels that may be tailored to the needs of the applications the network supports.

In order to effectively gather data from its source and transmit it to different data consumers, the system design makes numerous uses of the Pub-Sub paradigm. By gathering data only once and sending it to several receivers, this method maximizes bandwidth resources at the mobile edge. Furthermore, the Pub-Sub paradigm provides data consumers with flexibility by enabling them to dynamically establish, amend, or cancel subscriptions associated with the QoM class without affecting other users.

Figure 1.3. illustrates the high-level system architecture using solid lines for signaling and uncompressed data, and dotted lines for compressed data produced by a particular QoM class.

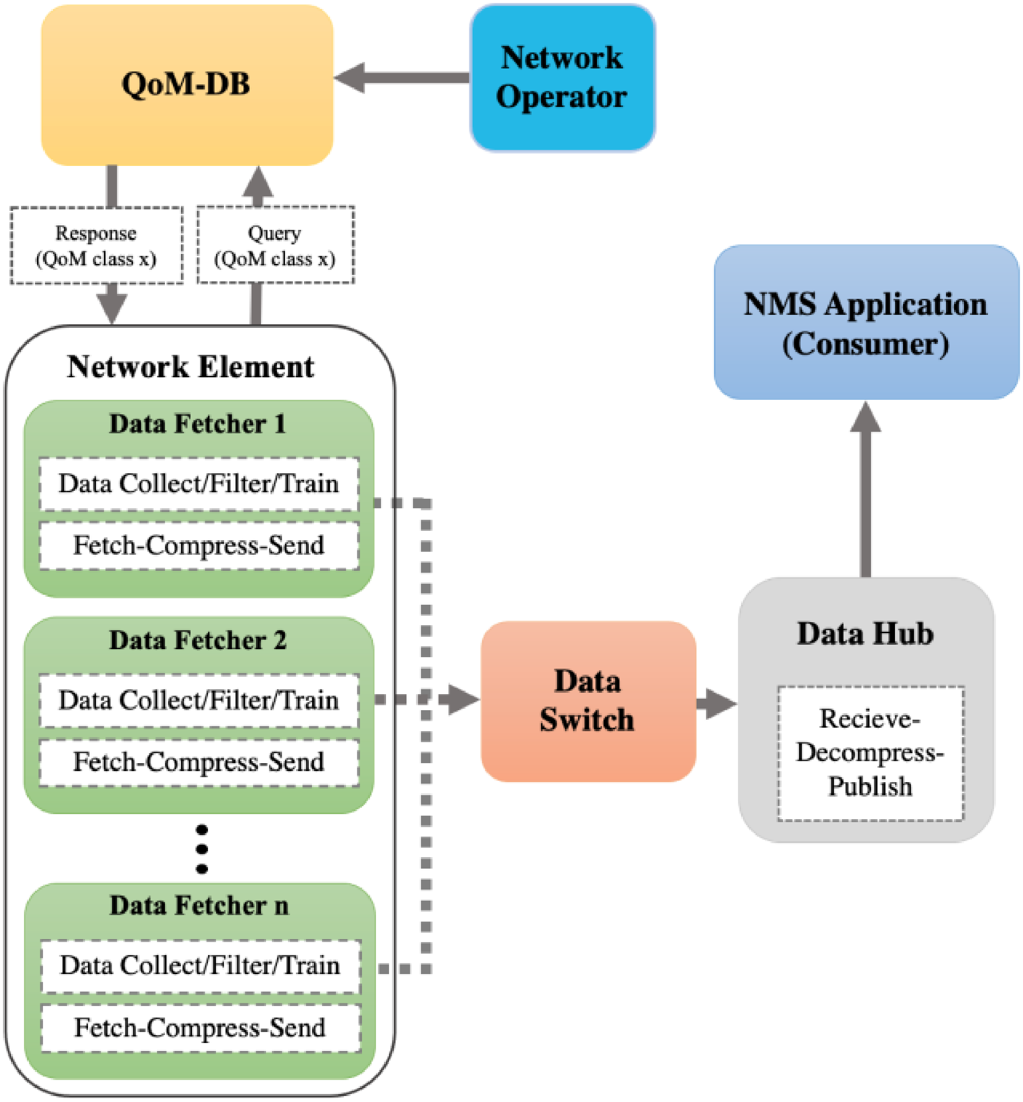


Fig. 1.3. The architectural framework of the (QoM) concept

There are several parts to setting up the QoM.

DF: This is a component that retrieves data from a NE or service, either independent or integrated. The data collecting function's chosen QoM class is used by the DF to filter out data segments with low information content. The DF minimizes computational and memory footprints by operating at the edge cloud, either at the MEC platform or a NE. The data producer and publisher in the QoM solution's Pub-Sub paradigm is the Data Foundation.

Raw M-plane data is collected, parsed, and then compressed according to the designated QoM class. The compressed and aggregated data is then sent to NMS applications that have subscribed to receive it. For example, KPI calculations are performed using predefined equations. To receive required QoM class definitions and KPI equations, the DF interfaces with a centralized QoMDB. The filtered and compressed data is also published by the DF.

Fetcher and Sender are the two sub-components that make up a DF. Responding to requests for subscription from the DH, the Fetcher interacts with NEs. In order to calculate KPIs based on subscriptions, it uses the KPI equation, saves M-Plane data as training data, receives raw MPlane data from the NE, and applies QoM class definitions from QoM-DB. Interfacing with the DS, the Sender performs the role of a data producer in the interim. Data requested by the subscriber is made available by the Sender once the KPI calculation has been completed by the Fetcher. Afterward, the compressed data is published to the DS by the Sender.

With enough of resources and a complete picture of all linked NEs, the DS is set up in the operator's central cloud. Boundary and data routing from DFs to DH are handled by the DS. Brokers such as Apache Kafka, which includes a Kafka cluster and a Kafka ZooKeeper, are examples of DS components that each data producer and data consumer has to be aware of. Creating and deleting Kafka topics based on subscriptions and keeping track of the status of messages consumed are the duties of the Kafka ZooKeeper in the DS, which also serves as the cluster's coordinator and admin.

For NMS applications, the DH provides filtered data sections. The DH starts data subscriptions, notifies the DS of new subscriptions, and sends subscribed data to NMS applications using a Pub-Sub model. Recognizing changes in subscriber numbers, updating counts for several customers sharing a membership, and providing information to interested customers are all part of the duties performed by DH.

The Kafka ZooKeeper in the DS keeps track of all the messages that the DH has eaten, including the offset of the most recent message ingested. It generates new Kafka topics for subscribers and eliminates topics that have no active users. In the event of a Kafka broker failure, each producer and consumer in the DS should be acquainted with at least one Kafka broker, providing redundancy advantages [1].

Between the network operator and the NEs, the QoM-DB serves as a central database. It makes it easier for NEs and network functions to communicate, enabling operators to keep up with KPI calculation formulas for unprocessed M-Plane data. For operators to specify required models, parameters, equations, and QoM class definitions, the QoM-DB offers interfaces. It also offers a query interface for applicable QoM classes to be used by DFs.

The definitions included in the QoM classes provide restrictions of losing data for particular KPIs. The DFs request equations for all subscribing KPIs from the NMS application over this interface. After receiving the KPI equations, the DF calculates the KPI and uses the supplied QoM class parameters for compressing the KPI data. These KPIs are based on one or more network counters; some may only use data from one counter, while others may combine information from many counters. Consequently, the KPI calculation process combines data from several counters into a single number.

The most popular metrics for keeping an eye on service quality are displayed in Figure 1.4.

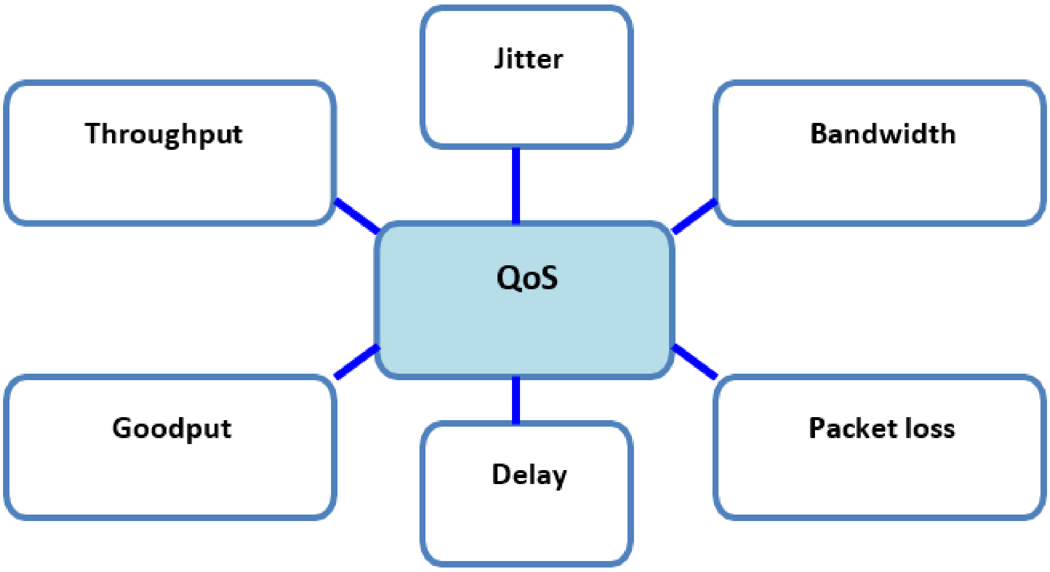


Fig. 1.4. Metrics for monitoring service quality

Applications including phone, video, and time-sensitive information require enterprise networks to provide reliable and quantifiable services as they move over the network. Businesses utilize QoS to meet the traffic demands of vital applications, such as real-time audio and video, and to stop quality degradation brought on by jitter, packet loss, and delays.

Organizations may get QoS by employing several tools and strategies such as traffic shaping and jitter buffers. To guarantee a particular degree of NT, many enterprises include QoS in their service-level agreement with their network service provider.

Despite their modest differences, CoS and QoS are occasionally used interchangeably. CoS technology takes a less detailed approach to traffic control and does not explicitly guarantee a bandwidth level of service. Whether someone says "CoS" or "QoS," they are probably talking about the same thing in many cases.

QoS parameters

A number of metrics may be used to quantitatively evaluate QoS parameters, including:

1. Packet loss: When network connections are overloaded, packets are discarded by switches and routers. Jitter and speech gaps can occur during real-time communication, including audio or video conversations, because of missed packets. Overflowing of the queue, or the line of packets waiting to be transferred, can result in packet loss.

2. Jitter: Caused by changes in routes, network congestion, and timing inconsistencies. Overly erratic behaviour can negatively impact both audio and visual communication quality.

3. Latency: Represents the amount of time it takes for a packet to go from one place to another. Latency should ideally be close to nil. Users may experience audio overlap and echo during a voice over IP conversation due to high latency.

4. Bandwidth: denotes a network communications link's ability to send the most data possible between two points in a predetermined amount of time. By effectively controlling bandwidth and assigning additional resources to applications with high priority with higher performance needs, QoS improves NT.

5. Mean Opinion Score: A method of measuring speech quality that uses a five-point rating system, with five being the best quality.

Organizations must follow a set of procedures while implementing QoS, as seen in Figure 1.5.

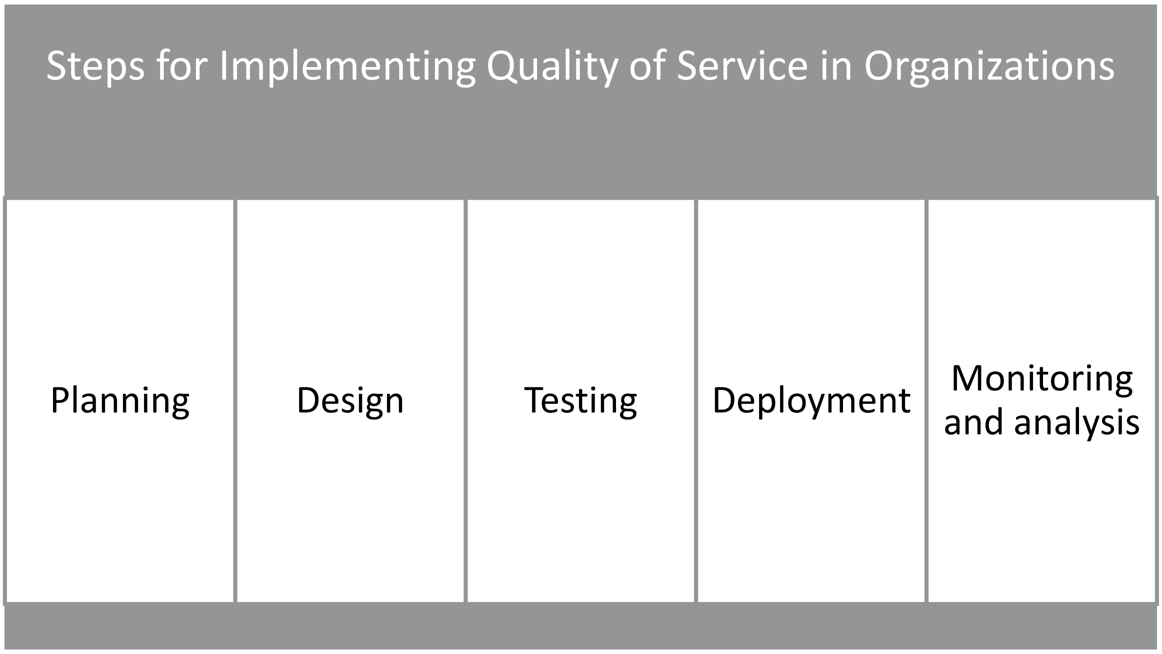


Fig. 1.5. Organizational QoS Implementation Steps

1. Planning: Determine the services required by each department, choose an appropriate model, and win over stakeholders.

2. Design: Keep track of any major software and hardware modifications and adjust the selected QoS model to the network architecture's particulars.

3. Testing: To find and fix any errors, assess QoS settings and rules in a controlled testing environment.

4. Deployment: Gradually introduce policies, either independently of QoS functions or per network segment.

5. Monitoring and analysis: To improve system performance overall, modify rules in response to performance data [1].

Three QoS models are available:

– Best Effort: This type of network is appropriate for those without infrastructure support or without QoS settings established since all packets have the same priority and delivery is not assured;

– IntServ: Applications seek resource reservations via a designated network path, and network devices monitor packet traffic to verify resource acceptance;

– DiffServ: This feature requires traffic classification depending on an organization's setup, setting up network components like switches and routers to handle various traffic classes with different priority.

However, IntServ is not scalable and consumes a large amount of network resources; the Resource Reservation Protocol and IntServ-capable routers are necessary for its implementation.

DiffServ Code Point can be used to classify traffic and favor voice over other types. Per-hop behavior can be used for QoS strategies like queuing and prioritizing.

QoS implementation is also influenced by the network architecture used. Although it can be expensive, an end-to-end QoS network with MPLS employs a single link. Monitoring network connections and enabling failover depending on performance concerns, SD-WAN makes use of many connectivity types, such as broadband and MPLS. For example, when a connection's packet loss exceeds a certain threshold, SD-WAN looks for a different connection.

The main benefit of using QoS is that it guarantees network accessibility and application functionality inside an enterprise. It ensures that data is sent over the network securely and effectively. Furthermore, QoS helps enterprises to make better use of the bandwidth they already have, preventing the need to improve network equipment in order to increase capacity.

Many methods are used in mobile networks for quality management and control (QoS, or quality of service). A selection of these is displayed in Figure 1.6.

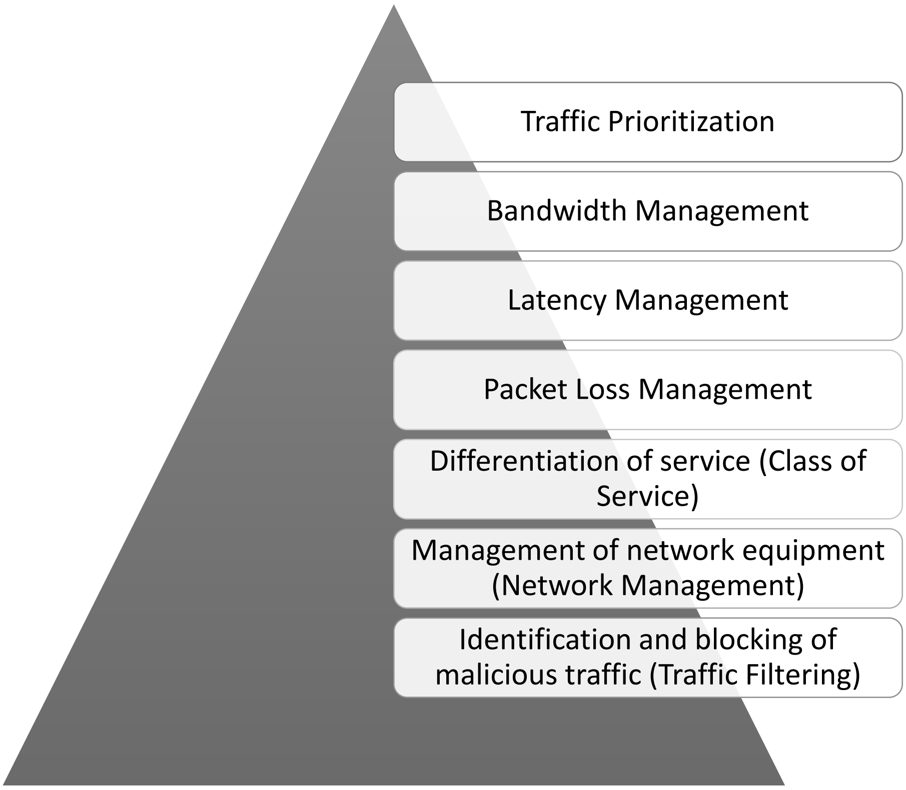


Fig. 1.6. Diverse Strategies for Quality Control and Management

1. Traffic Prioritization: You may rank critical apps or services according to importance by allocating varying levels of priority to different types of traffic. To guarantee better service, for instance, significant multimedia apps can be given a greater priority.

2. Bandwidth Management: Distributing and overseeing the bandwidth that is accessible to various users and apps. This might entail imposing bandwidth restrictions on particular kinds of data or imposing user limits.

3. Latency Management: Cutting down on routing channels and employing technologies that shorten data transmission times to minimize delays in data transfer.

4. Packet Loss Management: Employing techniques like correction codes or switching to different pathways to lessen packet loss in the network.

5. Differentiation of service (Class of Service): Traffic is divided into groups based on priority. To provide the best possible QoS, each class may have unique QoS settings.

6. Equipment management for networks: This involves keeping an eye on and managing networked devices to guarantee their dependability and efficiency.

7. Malicious traffic identification and blocking: To protect network and resource security, techniques are used to detect and stop unwanted or malicious traffic.

Combining these strategies can lead to complete quality control in mobile networks based on needs and use cases.

Among the particular advantages are:

– applications that are vital to the mission are equipped with the resources they require;

– managers are able to handle network traffic more skillfully;

– companies can reduce expenses by not having to make investments in brand-new network infrastructure;

– the experience of the user has improved.

The Drawbacks of High Service Quality

Setting QoS as a top priority has the drawback of not offering an identical user experience. Setting priorities according to the different elements of the data path(s) and service quality may not necessarily improve the general user experience (quality experience).

Limited Resource Availability: In networks, establishing QoS provisioning is quite difficult. Problems with QoS are caused by security features.

Routing: Both Preemptive and Reactive: Proactive routing requires a lot of resources, but reactive routing is slow. Delays are compounded by slow routing, which also uses more resources and shortens the device's battery life. In light of the stringent standards for service quality, these approaches' development and implementation are essential to guaranteeing peak performance and meeting user demands.

Monitoring several network characteristics, including throughput, latency, signal strength, packet loss, and more, is one way of doing traffic analysis. This makes it possible to gather statistical information on the state of the network and assess its effectiveness. Furthermore, traffic analysis aids in identifying traits and problems that could compromise the quality of communication.

Quantitative evaluation of NT is achieved through the use of measurement techniques for network metrics like latency and throughput. Test packets are sent, and the time it takes for them to be sent and received is measured, using specialized instruments and equipment.

Throughput, latency, and various other network metrics that are essential for guaranteeing QoS are calculated using this data.

By flooding the network with a lot of data, one may test throughput and latency by timing the transmission of the data and observing the resulting delay. This aids in locating any network flaws and restrictions that can affect service quality.

Moreover, 5G network quality may be measured and analyzed using simulation models. With the help of these models, different network operating situations may be replicated and their effects on service quality evaluated. They make it possible to test different network setups as well as management methods in order to find the best ones and enhance network functionality.

In addition to ensuring efficient administration of mobile networks, the adoption of network reliability analysis and assessment techniques offers users and applications high-quality service. Developing innovative techniques and doing research in this area are crucial steps toward the ongoing improvement and efficiency of 5G networks [1].

1.2. Requirements of basic services to the quality of packet transmission

The primary benefit of the following-generation network is its ability to transmit several types of traffic simultaneously and in high quality over a single communication channel. For instance, many services can be delivered via a single subscriber line: IP telephony (which uses packet switching for phone conversations), IPTV services (which provide pictures and videos over an IP network), and the Internet (which allows for file transfers, web page viewing, email, and other activities). When building multi-service networks, it is important to take into account the unique communication channel transmission requirements of each of these services (Table 1.1. provides an example).

Table 1.1

Quality of service requirements for different types of services

Quality of Service Parameters/Service Category	Loss of Packets P, %	Bandwidth Capacity C, kbit/s	Jitter J, ms	Packet Delay T, s
IP Telephony	0,1	64	<150	<300
Video Conferencing	0,8	2048	<30	<100
IPTV	1,5	10240	50	500
Data	0,1	2048	1000	1000
Video on Demand	0,05	4096	30	1000

Additionally, it's important to consider that different applications have distinct needs while developing a multi-service network in terms of network properties. A sample of these specifications may be seen in Table 1.2.

Table 1.2

Requirements for tenwork characterictics

Addition	Bandwidth	Delay	Jitter	Loss
Email	low	low	weak	weak
File transfer	high	low	weak	weak
Web access	average	average	weak	weak
Remote access	low	average	average	average
Audio to order	low	low	weak	low
Video to order	high	low	weak	low
Telephony	low	high	weak	low
Video conferences	high	high	weak	low

1.3. The relevance of the task of QoS standardization

Since the primary focus in the communication industry is on the customer, market changes help to foster greater competition amongst operators, which raises the quantity and QoS available.

The relevance of service quality concerns is growing in the current telecommunications growth. It is safe to say that in the near future, customers will want higher quality services in their interactions with communication operators, and all other parties involved in the service providing process will adopt them as well.

Consequently, maintaining the required level of service quality for customers falls under the purview of their interactions with communication network operators and necessitates regulation.

A system of national standards for service quality and service stage agreements are two examples of the pertinent regulatory documents that must be developed in order to enhance the quality of communication services provided under competitive conditions in the telecommunications services market.

The term QoS is now extensively used, not just for classic telephone networks (where it originated), but also for broadband, wireless, and IP-based multimedia services.

As defined by the ISO 8402 1994 dictionary, "a good quality is a group of features of an object which determine it's capacity to satisfy stated requirements." That being said, quality was defined in the 2000 ISO 9000 standard (which superseded ISO 8402) as the extent to which an individual's personal attributes fulfill the established criteria.

The ISO 8402 standard defines the terminology that are used to describe the quality of communication services. The ITU Recommendation E.800 provided the initial definitions of these terms. The text referred to QoS as "the total measurement of the operational variables of the product or service, that defines the degree of satisfaction that users have with the service".

The word QoS is widely used in standards, reports, and specifications, but neither defines it nor makes reference to one of the existent definitions, such that found in ITU

Recommendation E.800. There are thirteen definitions of QoS in this guideline, so you may understand the concept in a variety of situations.

Generally speaking, availability, usability, security, efficiency, and other traits unique to a certain service should all be taken into consideration when evaluating a service's quality.

Availability, continuity, and integrity are the three components of efficacy, which is the most significant of the attributes previously discussed.

QoS definitions and descriptions frequently refer to NP. A collection of criteria characterizing the network's or its component parts' capacity to carry out operations that guarantee user communication is known as the quality of network functioning. It is important to remember that the notion of network operating quality is not the same as the phrase QoS. User perception determines QoS, whereas individual NEs or the network's overall operational characteristics define the quality of network functioning. Still, QoS is influenced by network operation quality, which makes it one of its constituents.

Thus, QoS is defined by subjective indicators that represent the desired quality and user perception in addition to technical characteristics (quality indicators of network operation).

Apart from technical indications, QoS may be assessed from two distinct perspectives: that of the communication operator and the subscriber (user). Although the communication operator assesses the potential for delivering communication services and the efficient use of technological resources, the user assesses the quality of the service based on their level of satisfaction with the received service.

Consequently, it can be said that there is a connection between the communication operator's planning and attainment of service quality and the user's demands and perception of service quality from both perspectives.

The subscriber's evaluation of the service is based on customer preferences, which are defined by a number of factors related to the effectiveness of the network. A network's efficiency is measured by its capacity to handle, reliably transmit, and transfer data with high quality.

The ability of a network object to comply with specific requirements for processing traffic under specific internal circumstances, like the ratio among operational and nonoperational parts of that object, is one of the most crucial aspects of the quality of the network's functioning. The dependability, quality of data transfer, and resources and capabilities of the item all affect how efficiently its traffic processing functions.

One of the key elements influencing the supply of high-quality services is reliability. According to ITU Recommendation E.800, dependability is a word used to characterize a variety of characteristics, including availability, lack of failure, attributes that impact repair, and the availability of maintenance and repair.

The ability of an object to carry out the required function under specific conditions at a specified time or in a certain amount of a period of time when the necessary external resources are provided, is defined as readiness, which is central to the key components of reliability (MEK 60050, 1991).

It is required to follow ITU Recommendations E.862 and E.880 for determining dependability. The ITU Recommendation E.880 takes into account the problems associated with gathering operational data and utilizing it to assess the dependability of devices, networks, and services. It includes a list of data that has to be documented as well as details on the sources of data that are accessible and how they were collected. They also include a list of important indications that should be used in order to evaluate dependability when the system is in use.

Techniques for designing, running, and fixing communication networks are outlined in [2], taking into account potential losses in the event that service providers' and consumers' technical equipment malfunctions. These methods may be applied to raise the network's overall efficiency, identify the kind and quantity of spare parts needed, and set up the system for maintenance and repairs.

The proposal was adopted due to the importance of the issues surrounding the enhancement of communication network dependability in an open service market environment with growing competition. Reliability declines have the potential to cost communication network operators consumers and have a detrimental impact on their business's financial metrics. Furthermore, a technical breakdown might result in a denial of service, which could cause income loss and direct damages in the form of potential fines for communication network providers.

Appropriate indicators are utilized to guarantee the measurement of the majority of the qualities listed in ITU Recommendation E.800. ITU Recommendation G. 1000 provides a generic concept for QoS, which was established to offer a comprehensive approach to QoS that can be used to network construction and planning as well as QoS monitoring. The availability of advancements in QoS and NP, as outlined in ITU Recommendations E.800, I.350, and Y.1540, is taken into consideration throughout concept development. A practical approach to quality management is provided by ITU Recommendation G.1000, which covers the definitions of quality from ISO 8402's general definition to ITU Recommendation E.800's specific QoS criteria. Additionally, Recommendations I.350 and Y.1540's recommendations for assessing network functioning quality and ETSI ETR 003's QoS definition matrix can be used to break down all the components of QoS. An 11x7 matrix that may be used to ascertain the quality standards of any telecommunication service is mentioned in the ITU Recommendation G.1000.

Reliability, speed, availability, accuracy, flexibility, security, and simplicity are the criteria for service quality that are displayed on the horizontal axis of the matrix. The functions related to the service are displayed on the vertical axis, and they include service management, invoicing, and network/service management that is done by the client. A set of the service's operating characteristics may be ascertained with the aid of the criteria presented in the matrix. Four points of view are presented in the recommendation on QoS: client-required QoS, client-perceived QoS, client-offered QoS, and client-achieved or given QoS. ITU Recommendation E.802's methodological guidelines for establishing QoS parameters and criteria are based on this idea.

The phrases QoS and NP are defined using several ideas, such as criteria, indicators, and parameters of network functioning or QoS, as well as norms for those indicators or parameters.

As a result, the user anticipates receiving excellent services from a communication operator, the impartiality of which is determined by quality metrics. These indications are given by the features of the communication network's operation and the technical specifications for the services.

Ensuring the quality of the service may be achieved by meeting the stated requirements for different service quality indicators and network functioning. It is imperative that quality indicators be acknowledged by both independent expert bodies and users. When it comes to keeping an eye on the quality of network operations and determining the root causes of service quality breaches, internal indicators are crucial. The service level agreement's service standards presuppose a connection between the service's quality indicators and its customer attributes.

International groups for QoS standardization:

1. ISO (International Organization for Standardization).
2. IEC TC 56 (International Electrotechnical Commission Dependability Technical Committee).
3. ITUT (Telecommunication Standardization Sector of the International Telecommunication Union).
4. ETSI (European Telecommunications Standardization Institute).
5. Eurescom (European Institute for Research and Strategic Studies in Telecommunications).
6. IETF (Internet Engineering Task Force).
7. INTUG (International Telecommunication Users Group).
8. ETNO (European Telecommunications Network Operators Association).
9. QuEST Forum (Quality Excellence for Suppliers of Telecommunications).
10. TIA (Telecommunications Industry Association).
11. ANSI (American National Standards Institute).
12. TMF (International Network Management Forum).

CONCLUSION TO CHAPTER 1

Ensuring the dependable and effective functioning of contemporary communication technology heavily relies on QoS. You can ensure effective adoption of new technologies, optimal usage of network resources, support for a variety of services, connection reliability, and user demands fulfillment through QoS control and management.

Mobile networks may be managed and controlled using a variety of techniques, such as service differentiation, bandwidth management, traffic prioritization, delay and packet loss reduction, etc. All these strategies have their benefits and may be used in different situations and for different kinds of needs.

Throughput, packet loss, jitter, delay, and other indicators are used to measure QoS factors. Evaluation of the network's performance and present condition is made possible by their measurement. Also employed are techniques for traffic modeling and analysis.

National and international regulatory bodies must create appropriate regulations in order to regulate QoS-related concerns. A few groups, including as ITU, ISO, and ETSI, are working on standardization in this field. Regarding the definition and assessment of indicators for communication service quality, they offer advice.

Therefore, one of the most important tasks for mobile carriers is to provide the necessary degree of QoS. User satisfaction will rise and networks' efficiency will be maximized with the continued development of technologies for network quality study and measurement.

CHAPTER 2
REQUIREMENTS AND CHARACTERISTICS OF 4G AND 5G TECHNOLOGIES

2.1. Long Term Evolution

For a number of years to come, UTRA, a third-generation system improved by HSPA, should remain competitive. But in December 2004, the industry that developed 3GPP technology launched the LTE initiative, realizing that progress was necessary. The goal of this research was to investigate the needs for Evolved UTRA (E-UTRA), an evolved air interface.

Following E-UTRA/LTE requirements were defined by the study's findings, which were recorded in 3GPP TR 25.913 (Rel-7):

1. Significantly higher peak rates of data, such 50 Mbps uplink and 100 Mbps downstream.
2. Greater bitrates at cell borders, supposing the positions of the present sites.
3. A higher spectrum efficiency compared to Rel-6, around 2-4 times higher.
4. A lower delay.
5. Scalable bandwidth to enable more freedom in frequency distribution.
6. A reduction in operating and capital costs, including backhaul.
7. Acceptable power consumption, cost, and complexity of the system and terminal.
8. Assistance in integrating with both non-3GPP-specified systems and currently in use 3G systems.
9. Effective support for a range of services, particularly in the PS domain (such as presence and voice over IP).
10. Low mobile speed optimization that supports high mobile speeds (up to 500 km/h).

In accordance with the specifications of E-UTRA/LTE, 3GPP TR 25.912, a feasibility study for enhanced UTRA and UTRAN, was created by the Rel-7 study. In September of

2006 to March 2009, normative work on E-UTRA/LTE was conducted in the Rel-8 standards.

Concurrently, research was conducted on the evolution of 3GPP System Architecture. In order to accommodate different RAT, the goal was to develop a framework for the evolution or migration of the 3GPP systems to a higher-data-rate, lower-latency, packet-optimized system. Following comparable normative Rel-8 work, this work-which was centered on the PS domain and assumed to provide voice service in this domain-produced 3GPP TR 23.882 (Rel-8).

Though "Evolved UTRA" originally implied a step-by-step enhancement of the current third generation UMTS system, it finally transformed into a unique radio access technology:

With the help of shared channels and HSPA, UMTS finally transitioned from a circuit-switched to a packet-switched system. Dedicated packet-switched technology, on the other hand, is what LTE is.

UMTS used CDMA, while LTE uses SC-FDMA for uplink (UE => eNodeB) and OFDMA for downlink (eNodeB => UE.

(Note 1: SC-FDMA, sometimes called DFT-S-OFDM, may achieve lower peak-to-average power ratios (PAPR), which improves the efficiency and design of the UE power amplifier.)

LTE has six alternative channel bandwidths: 1.4/3/5/10/15/20MHz, in contrast to UMTS's 5MHz channel bandwidth.

In LTE, the functions of the RNC are shared between eNodeB and the main network, creating a flatter and more straightforward radio architecture in comparison to UMTS, which has an RNC between NodeB and the cellular network.

All of these protocols, however, share a 10 ms radio frame, allow FDD and TDD modes, and guarantee complete compatibility between GSM/GERAN/EDGE and LTE/E-UTRA.

LTE-Advanced

Four key factors contributed to the advancement of the fourth generation of mobile communication systems: the 2007 WRC-07 proposal for additional spectrum allocation to

IMT systems, which included the 450 MHz band, UHF band (698-960 MHz), 2.3-2.4 GHz band, and C-band (3400-4200 MHz), as well as the 2008 ITU-R call for an IMT-Advanced radio interface.

The key components of IMT-Advanced were outlined in ITU-R M.1645 (targets above IMT-2000) and M.2134 (requirements for IMT-Advanced):

1. Ensuring broad worldwide functioning while affordably retaining flexibility for a wide range of services.

2. Ensuring that services operate both on fixed networks and within IMT.

3. The capacity to work with different radio access systems.

4. Offering top-notch mobile services.

5. Creating user gear that is appropriate for usage worldwide.

6. Creating equipment, services, and applications that are easy to use.

7. Making global roaming possible.

8. Achieving improved peak data rates – 100 Mbit/s for high mobility and 1 Gbit/s for low mobility—to enable advanced services and applications.

In March 2008, 3GPP launched an early Rel-9 research item (FS_RAN_LTEA, RP-091360) to define LTE-Advanced in 3GPP TR 36.913, while also concluding its Rel-8 LTE WI. The requirements stated were that LTE-Advanced must develop from Release 8 LTE, retain all 3GPP TR 25.913 LTE specifications, and reach or surpass IMT-Advanced requirements by the ITU-R timeframe. The distinction between "Advanced E-UTRA" and "LTE-Advanced" should be made clear. Still operating under Rel-8, RAN #40 approved 3GPP TR 36.913, "the requirements for additional developments for E-UTRA (LTE-Advanced)," in June 2008.

Furthermore, a study was started under 3GPP TR 36.912 in March 2008 to investigate the potential for developing E-UTRA (LTE-Advanced). The goal of this research was to evaluate possible LTE improvements, like:

1. Creating a greater bandwidth by combining many component carriers with a combined bandwidth of up to 20 MHz.

2. Using a maximum of eight layers for downlink and four for uplink when implementing spatial multiplexing.

3. Coordination of various points of transmission and reception is introduced to improve cell-edge performance, overall system throughput, and high data rate coverage.

4. Including relaying capabilities to increase throughput at the cell edge, optimize coverage for high rates of data, group mobility, transient network deployment, and more coverage regions.

5. Fulfilling and exceeding the prerequisites for IMT-Advanced.

The system of information was completed at RAN #46 and RAN #47 on March 2010, after additional revisions to this TR 36.912, which was accepted in September of 2009 (RAN #45) as Rel-9 TR.

Release 10 saw the start of specific work items that included LTE advancements that were covered in the Rel-9 research for LTE-Advanced. Among these were:

1. In December of 2009 to June 2011, LTE carrier aggregation (LTE_CA) (RP-100661).

2. From December 2009 to June 2011, LTE_UL_MIMO (UL multiple antenna transmission) (RP-100959).

3. LTE_eDL_MIMO: Improved Downlink Multiple Antenna Transmission since December 2009 to March 2011 (RP-100196).

4. CoMP Operation for LTE: Initially a study in Rel-10, it was finished in Rel-11, and Rel-13 and Rel-15 saw more improvements.

5. LTE relays (LTE_Relay) from June 2011 to December 2009 (RP-110911).

6. Latency reduction: in Rel-10, development was stopped, however in Rel-14, L2 latency reduction was implemented.

7. Additional improvements to the LTE MBMS (MBMS_LTE_enh) between June 2010 and March 2011 (RP-101244).

8. From March 2010 to June 2011, LTE Self Optimizing Networks (SON) upgrades (SONenh_LTE) (RP-101004).

9. Since December of 2009 to June 2011 (RP-100360), driving tests for UTRAN and E-UTRAN (MDT_UMTSLTE) were reduced in size.

The LTE standards created in Rel-8 and Rel-9 are merged with all LTE upgrades in Rel-10 and beyond, thus it's crucial to emphasize that there is no separate "LTE-Advanced" radio access technology.

Additionally, 3GPP made contributions to the IMT-Advanced project of ITU-R, including a final submission with self-evaluation findings in September of 2009 (RP-090939) during RAN #41 and RAN #45, respectively, and an early preliminary input in September of 2008 (RP-080763).

The Radiocommunication Assembly affirmed LTE-Advanced as the IMT-Advanced radio interface technology in January 2012 by approving ITU-R Recommendation M.2012, "Detailed requirements of the terrestrial radio interfaces of IMT -Advanced" (RP-120005). The most recent improvements to ITU-R M.2012 are notably added by 3GPP on a biannual basis.

LTE-Advanced Pro

Rel-13 (ASN.1 freeze: March 16, September 14–December 15) [3]

All LTE innovations after Rel-13, excluding those connected to 5G, are branded as "LTE Advanced Pro." For example, the following enhancements are present in Rel-13 (September of 2014 to December of 2015, ASN.1 freeze: March 2016):

1. IoT via narrowband.
2. Additional improvements for MTC to the LTE Physical Layer.
3. LTE dual connectivity improvements.
4. Dual Connectivity is Extended in E-UTRAN.
5. LTE-based Licensed-Assisted Access (LAA).
6. FD MIMO/Elevation Beamforming for LTE.
7. UTRA and LTE Indoor Positioning Enhancements.
8. Additional Improvements to the E-UTRAN Drive Test Minimization Process.
9. Improved LTE Proximity Services from Device to Device.
10. LTE User Equipment Multicarrier Load Distribution.
11. Support for point-to-multipoint, single-cell LTE transmission.
12. Improved Signaling for CoMP for LTE Inter-eNB.
13. RAN improvements for longer DRX over LTE.

14. Enhancing Interworking and Integrating LTE-WLAN Radio Level.

15. Legacy WLAN is supported via LTE-WLAN RAN Level Integration.

16. RAN facets of data communication congestion management that are application-specific.

17. RF specifications for the Active Antenna System at the Base Station.

18. SON for deployments using AAS.

19. Exclusive Core Networks.

20. RAN Features of LTE RAN Sharing Improvements.

21. Stricter specifications for testing UEs' multi-antenna reception capabilities.

22. UE core specifications for 64 QAM uplink.

23. Four Rx antenna ports for LTE DL.

Rel-14 (ASN.1 freeze: June 17, Dec. 15-March 17) [3]

Release 14 (ASN.1 freeze: June 2017; December 2015–March 2017) without duplicating already-existing material, a number of enhancements and additions to diverse wireless communication technologies were made. Among them are:

1. Improvements to the Narrowband Internet of Things; 2. Upgrades to MTC for LTE.

2. Introducing eNB-ID and Cell-ID flexibility inside the E-UTRAN.

3. LTE's improved Licensed Assisted Access.

4. Assistance with LTE-based V2X services and Vehicle-to-Vehicle services based on the LTE sidelink.

5. Advances in LTE Full-Dimension Multiple Input Multiple Output.

6. The downlink Multiuser A superposition Transmission for LTE.

7. Swapping of the LTE component carriers' Sounding Reference Signal.

8. Additional improvements to indoor location in LTE and UTRA.

9. LTE uplink capacity augmentation.

10. LTE evolved eMBMS advancements.

11. Strategies to lower Layer 2 latency in LTE.

12. Further upgrades to mobility inside LTE networks.

13. Improvements to voice and video quality for LTE.

14. Improved LTE-WLAN Aggregation and LTE WLAN Radio Level Integration via IPsec Tunnel.

15. Progress made in Dedicated Core Networks for LTE and the UMTS.

16. Measurement gap enhancement for LTE.

17. Specifications for a new category of UE based on Cat. 1 for LTE that has a single receiver.

18. Improvements to LTE performance in high-speed settings.

19. Adding four receiver antennas ports for LTE downlink with carrier aggregation.

20. Multi-band base station testing including three or more bands.

21. Stricter performance standards to confirm UEs multi-antenna reception.

ASN.1 freeze: September 18, Rel-15 (March 17–June 18) [3]

Rel-15 (March 17–June of 18, ASN.1 freeze: Sept. 18) witnessed a number of developments in several fields:

1. NB-IoT has received more enhancements.

2. Additional improvements were made to MTC for LTE.

3. There have been improvements to LTE operating in unlicensed spectrum.

4. The LTE-based V2X phase 2 was unveiled.

5. The LTE CoMP Operation received more improvements.

6. The accuracy of UE positioning was improved using LTE.

7. DL 1024 QAM was launched and high-capacity stationary wireless networks were improved.

8. In order to reduce drive testing, Bluetooth and WLAN measurement collecting is used in LTE.

9. The introduction of Quality of Experience Measurement Collection in E-UTRAN was made for streaming services.

10. LTE introduced UL data compression.

11. There are now more E-UTRAN data carriers.

12. New video features were added specifically for LTE.

13. With an emphasis on Ultra Reliable Low Latency Communication, LTE experienced a decrease in TTI in addition to processing time.

14. A connection was made between 5G-CN and LTE.

15. Aerial Vehicles now have improved LTE support.

16. Actions were made to enhance the use of LTE carrier aggregation.

17. UE specifications were established to network-based CRS interference reduction in LTE.

18. UE specifications with 8Rx antenna ports have been provided for LTE DL.

19. Base Stations now have more stringent criteria for Active Antenna Systems in terms of Radio Frequency and EMC.

ASN.1 freeze date: June 20, Rel-16 (June 18–20) [3]

Rel-16 (June 18–20, the ASN.1 freeze: June of 20) brought forth a number of improvements to different areas without duplicating information:

1. More NB-IoT enhancements were put into practice.
2. With the advent of new MTC technologies, LTE saw significant improvements.
3. There was an improvement in Downlink Multiple Input Multiple Output efficiency for LTE.
4. E-UTRAN had a rise in improved mobility.
5. LTE now includes connectivity for the NavIC Navigation Satellite System.
6. More work was done on improving LTE performance in high-speed situations.
7. One noteworthy development was the arrival of 5G terrestrial broadcasting based on LTE.
8. A number of tasks were started, motivated by NR and LTE, such as:

– using NR sidelink to integrate 5G V2X;

– improvements in Carrier Aggregation and Multi-RAT Dual-Connectivity (LTE, NR);

– enhancements to UE radio capability signaling, emphasizing NR/E-UTRA elements;

– the architecture of eNodeB(s) for NG-RAN and E-UTRAN has evolved;

– presenting capability set(s) to radio specifications that are multi-standard.

Rel-17 (from June 20 - March 21, with a June 22 ASN.1 freeze scheduled) [3]

Rel-17 (from June 20 - March 21, the ASN.1 freeze planned for June 22) adds further LTE-MTC and NB-IoT enhancements. It involves adding more LTE bands for UE types M1/M2/NB1/NB2, expanding LTE Carrier Aggregation combinations, and supporting NB-IoT/eMTC in non-terrestrial networks.

In the context of 5G terrestrial broadcast, additional bands and capacity allotment are planned. The advancements fueled by LTE and NR include a variety of projects:

1. Multi-RAT Dual-connection advancements to improve connection even further.
2. Support for LTE/NR installations with multiple SIM cards.
3. eNB(s) architectural evolution for NG-RAN and E-UTRAN.
4. Better data gathering in NR standalone and Multi-Radio Dual Connectivity for Self-Organising Networks and Minimization of Drive Tests.
5. Continuous improvements to Multi-RAT-Dual Connectivity and RRM for NR.
6. Improvements to Multi-RAT-Dual Connectivity and NR measuring gap capabilities.
7. Users Plane Integrity Protection support in architectures with EPC connections.
8. The high-power UE (the power category 2) for EN-DC is introduced.
9. Band combination specifications for one NR/LTE V2X PC5 band and concurrent operation of the NR/LTE Uu bands/band combinations.
10. Investigation of sharing of LTE/NR spectrum in LTE band 40/NR band n40.
11. The definition of LTE/NR Dual Connectivity, NR Supplementary Uplink, and NR Carrier Aggregation/Dual Connectivity's simultaneous Rx/Tx band combinations.
12. Additional detection of Dual Connectivity band combinations in LTE/NR situations.

Rel-18 (ASN.1 freeze scheduled for March 24 and running from March 22 to December 23) [3].

Advances in the non-terrestrial network domain of the IoT are covered by Rel-18 (from March 22 to 23 of December, with the ASN.1 freeze expected for March 24). The LTE TDD band is also expected to be introduced in the 1,670–1,675 MHz frequency range. Tasks like the following are on the work agenda, which is led by LTE & NR:

1. Better In-Device Co-existence for MR-DC and NR.

2. Applying ML and AI to NG-RAN.

3. Developments in NR solo and Multi-Radio Dual Connectivity data collecting for Self-Organizing Networks and Minimization of Drive Tests.

4. Both NR and LTE Base Station/ UE Electromagnetic Compatibility improvements.

5. Additional improvement of Radio Frequency specifications in frequency range 1 for NR and EN-DC.

6. Assistance in deploying EN-DC/NR-CA non-collocated within the band.

7. Continuous improvements for both NR and MR-DC measurements with and without gaps.

2.2. 4G Network Architecture

Three parts make up the framework of the 4G wireless network system: UE, eNB, and EPC. The EPS, which includes the radio access networks E-UTRAN and the ePC, is often called the 4G network system. User data management, user data transfer, and user identity verification are the main responsibilities of the core network EPC. Along with some essential network tasks, the 4G system's radio component combines features from NodeB and eNB. Figure 2 shows the particular framework. In essence, LTE, SAE, and IMS may be combined to form the structure of the 4G network. IMS handles the transport of media services like voice in the 4G network, whereas LTE stands for the long-term evolution of the air interfaces and SAE for the advancement of the system architecture.

According to GPP, the following are the main features of the 4G base architecture: When it comes to control signals, including access for users' control, services bearers' control, and handover control, MME acts as the control core. In addition to serving as a buffer for downlink data packets, the Serving Gateway is mostly in charge of sending data among the base stations and public data gateways while serving as an anchor point during locally base station transitions. PDN Gateway is the anchor point for data carriers and handles many tasks such as forwarding packets, packet parsing, basic service pricing, commercial QoS management, and more. Home Subscriber Server, or HSS, is a database that holds user contracts, which include user location, user identity, user security control, and user policy control information. The policy executor at the gateway then puts the chosen and signed contract into practice. at conclusion, the PCRF, or Policies and Charge Rules Function, performs policy control and charge control. It does this by figuring out and sending the user's service consumption and billing strategy.

Interaction between Rel-15 5G Phase 1 and the rel-16 5G Phase 2 of IMT-2020 For Business and 3GPP 2014-2015 is depicted in Figure 2.1. protocol structure. Additionally explained are the R15 and R16 Basic versions. Figure 2.2. displays the design of the EPS network, whereas Figure 2.3. displays the QoS architecture of the 4G LTE network.

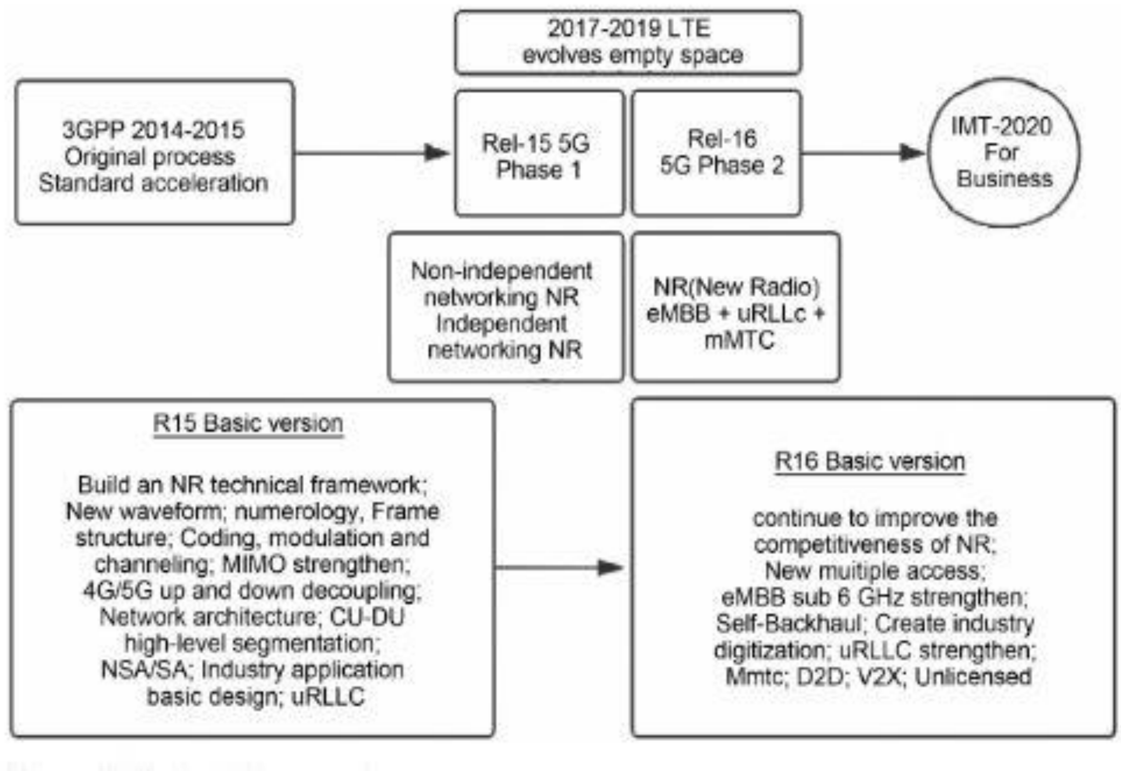


Fig. 2.1. Protocol framework

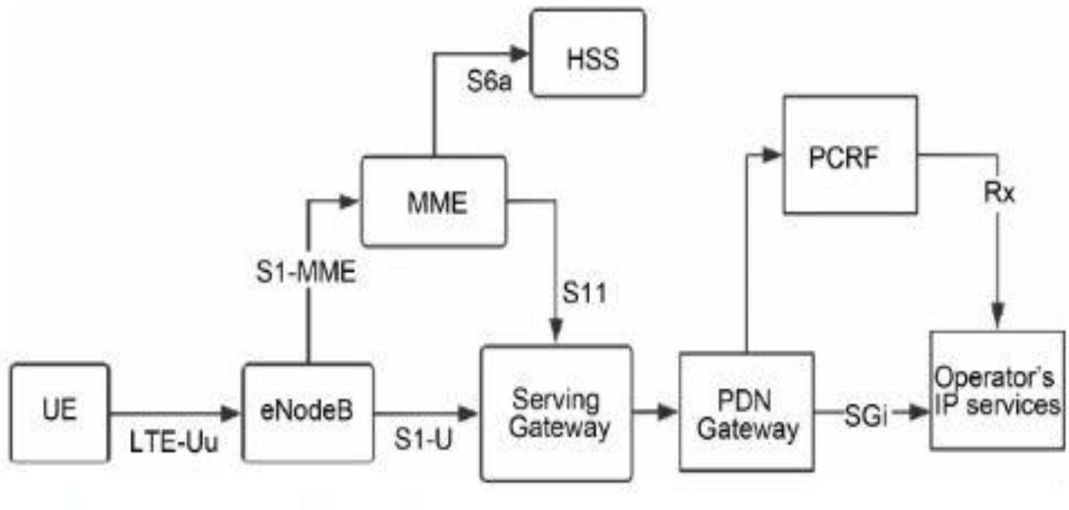


Fig. 2.2. EPS network architecture

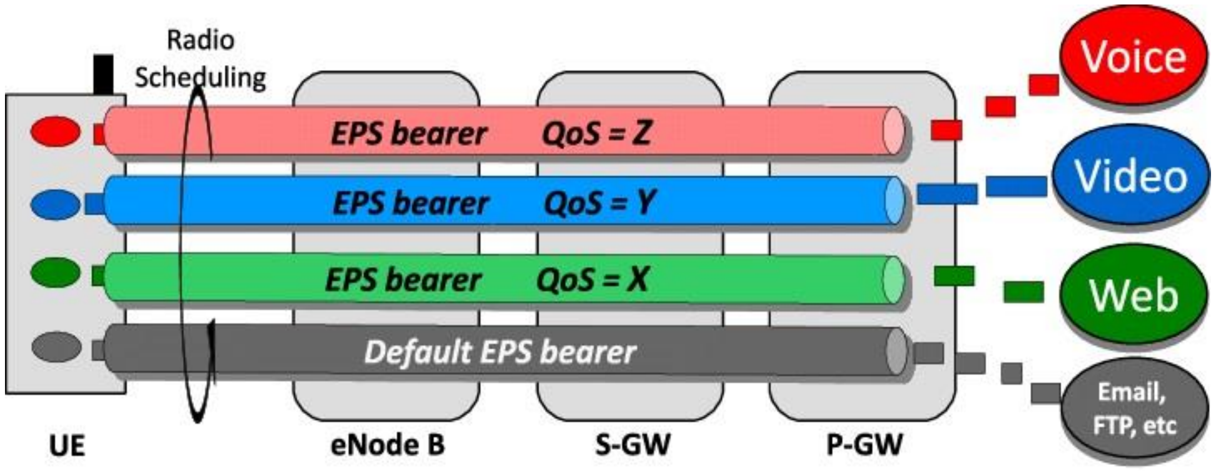


Fig. 2.3. 4G LTE network QoS architecture

The requirements listed in Table 2.1 below are specific to each allocated LTE QCI and service in the 4G LTE network.

Table 2.1

LTE QCI and Service-Specific Requirements

QCI	Resource Type	Priority Level	Packet Delay Budget (Note 13)	Packet Error Loss Rate (Note 2)	Example Services
1 (Note 3)	GBR	2	100 ms (Note 1, Note 11)	10^{-2}	Conversational Voice
2 (Note 3)	GBR	4	150 ms (Note 1, Note 11)	10^{-3}	Conversational Video (Live Streaming)
3 (Note 3, Note 14)	GBR	3	50 ms (Note 1, Note 11)	10^{-3}	Real Time Gaming, V2X messages Electricity distribution – medium voltage
4 (Note 3)	GBR	5	300 ms (Note 1, Note 11)	10^{-6}	Non- Conversational Video (Buffered Streaming)
65 (Note 3, Note 9, Note 12)	GBR	0.7	75 ms (Note 7, Note 8)	10^{-2}	Mission Critical user plane Push To Talk voice (e.g. MCPTT)
66 (Note 3, Note 12)	GBR	2	100 ms (Note 1, Note 10)	10^{-2}	Non-Mission-Critical user plane Push to Talk voice

Continuation of the Table 2.1

67 (Note 3, Note 12)	GBR	1.5	100 ms (Note 1, Note 10)	10^{-3}	Mission Critical Video user plane
75 (Note 14)	GBR	2.5	50 ms (Note 1)	10^{-2}	V2X messages
5 (Note 3)6	Non-GBR	1	100 ms (Note 1, Note 10)	10^{-6}	IMS Signaling
67 (Note 4)	Non-GBR	6	300 ms (Note 1, Note 10)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, p2p file sharing, progressive video, etc.)
7 (Note 3)	Non-GBR	7	100 ms (Note 1, Note 10)	10^{-3}	Voice, Video (Live streaming) Interactive Gaming
8 (Note 5)	Non-GBR	8	300 ms (Note 1)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, p2p file sharing, progressive video, etc.)

The end of the Table 2.1

9 (Note 6)	Non-GBR	9	300 ms (Note 1)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, p2p file sharing, progressive video, etc.)
69 (Note 3, Note 9, Note 12)	Non-GBR	0.5	60 ms (Note 7, Note 8)	10^{-6}	Mission Critical delay sensitive signaling(e.g. MC-PTT signaling, MC Video signalling)
70 (Note 4, Note 12)	Non-GBR	5.5	200 ms (Note 7, Note 10)	10^{-6}	Mission Critical Data (e.g. example services are the same as QCI 6/8/9)
79 (Note 14)	Non-GBR	6.5	50 ms (Note 1, Note 10)	10^{-2}	V2X messages
80 (Note 3)	Non-GBR	6.8	10 ms (Note 10, Note 15)	10^{-6}	Low latency eMBB applications (TCP/UDP-based); Augmented Reality

LTE QCI and Service-Specific Requirements:

1. To account for the delay between a radio base station and a Packet Control and Enforcement Function (PCEF) in the radio interface, subtract 20 ms from a given PDB. This delay is an average of situations in which the PCEF is situated both close to the radio base station (about 10 ms) and far from it (about 50 ms), for example, when roaming with home-

routed traffic. Since roaming is a less common circumstance, subtracting this average number from the PDB should, in most cases, deliver the necessary end-to-end speed. Notably, the PDB establishes a maximum value; in general, actual packet delays-particularly for GBR traffic-should be less than the PDB for a given QCI provided the UE keeps the radio channel quality adequate.

2. The packet losses resulting from non-congestion between a PCEF and the radio base station are deemed insignificant. All of the radio interfaces between a UE and the radio base station is covered by the PELR provided for a standardized QCI.

3. When an operator-controlled service is involved in QCI association, it usually occurs when a corresponding committed EPS bearer has been established or modified in E-UTRAN, at which point the uplink and downlink packet filters of the SDF aggregate are known.

4. To give MPS subscribers priority over non-real-time data (such as TCP-based services and apps), this QCI can be used for MPS.

5. Each subscriber or subscriber group can utilize QCI for a specific "premium bearer" (such as one connected to premium content). In these situations, at the exact moment of SDF aggregate permission, the uplink and downlink packet filters of the SDF aggregate are known. Or it can be used as the UE/PDN default bearer for "premium subscribers".

6. For non-privileged subscribers, this QCI is often utilized for the UE/PDN default bearer. The usage of Aggregate Maximum Bit Rate on the default bearer allows subscribers in the same PDN with the same QCI to be distinguished from one another.

7. Deducting a 10 ms delay by the PDB is required to get a packet-delay budget in the radio interface for mission-critical services, presuming the PCEF is situated close to the radio base stations (around 10 ms).

8. To accommodate appropriate battery-saving strategies, PDB requirements for certain QCIs can be eased in both RRC Idle and RRC Connected modes, provided that they do not exceed 320 ms for the first packet(s) in a downlink data or signalling burst.

9. QCI-5 is not utilized for signaling for the bearer using QCI-65 as the user plane bearer; instead, QCI-65 and QCI-69 are intended to be used in tandem for Mission Critical

Push to Talk service. When compared to IMS signaling, the expected amount of traffic per UE will be comparable or lower.

10. PDB requirement for these QCIs can be loosened for the initial packet(s) in a downlink data or signalling burst in the RRC Idle and RRC Connected modes to enable battery-saving approaches.

11. Of order to facilitate battery-saving approaches, PDB requirements for certain QCIs can be loosened for the initial packet(s) of a downlink data or signalling burst when in RRC idle mode.

12. Only the network side may request an assignment of this QCI value; requests from the UE or any app operating on the UE are not allowed.

13. The PDB does not apply to NB-IoT or WB-E-UTRAN when Enhanced Coverage is utilized.

14. The V2X messages specified in TS 23.285 can be sent using this QCI.

15. To calculate the packet's delay budget for the radio interface, subtract 2 ms from the provided PDB to account for a delay between a PCEF and the radio base station.

The table "LTE QoS Parameters for Different Services" outlines the specific QoS parameters allocated to various LTE QCI and corresponding services in a 4G LTE network. These parameters include resource type, priority level, PDB, PELR, maximum data burst volume, data rate averaging window, and example services for each QCI. This comprehensive overview assists in defining and optimizing the network's performance tailored to the unique requirements of diverse services such as Discrete Automation, Intelligent Transport Systems, and Electricity Distribution-high voltage.

Table 2.2

LTE QoS Parameters for Different Services

QCI	Resource Type	Priority Level	Packet Delay Budget (Note B1)	Packet Error Loss Rate (Note B2)	Maximum Data Burst Volume (Note B1)	Data Rate Averaging Window	Example Services
82 (Note B6)	GBR	1.9	10 ms (Note B4)	10^{-4} (Note B3)	255 bytes	2000 ms	Discrete Automation (NS 22.278 clause 8 bullet g, and TS 22.261)
83 (Note B6)	GBR	2.2	10 ms (Note B4)	10^{-4} (Note B3)	1354 bytes (Note B5)	2000 ms	Discrete Automation (NS 22.278 clause 8 bullet g, and TS 22.261)
84 (Note B6)	GBR	2.4	30 ms (Note B7)	10^{-5} (Note B3)	1354 bytes (Note B5)	2000 ms	Intelligent Transport Systems (TS 22.261)
85 (Note B6)	GBR	2.1	5 ms (Note B8)	10 (Note B3)$^{-5}$	255 bytes	2000 ms	Electricity Distribution- high voltage (TS 22.278 and TS 22.261 and Annex D)

Key Considerations in LTE QoS Implementation and EPS Bearer Management:

1. Bursts whose volume does not surpass the Maximum Dataset Burst Volume are eligible for use with the PDB.

2. Packets that do not meet the criteria for Maximum Data Bursting Volume and GBR but do not fall below the PDB are included in the Packet Errors Loss Rate for unsuccessful packet delivery across the access network.

3. Bursts bigger than the Maximum Data Burst Volume or data rates higher than the GBR are considered best effort. These could be discarded in order to satisfy the Packet Errors Loss Rate and make room for further packets.

4. In order to calculate the delay in packets budget that applies to the radio interface, deduct one millisecond from the provided PDB for the delay of one millisecond among a PCEF and the radio base station.

5. On an IPv6-based, IPSec-protected GTP connection to the eNB, the maximum Data Burst the volume has been set at 1354 bytes to avoid IP fragmentation. This number is computed in accordance with TS 23.060 [4] Annex C, and it is then trimmed by 4 bytes to provide room for a GTP-U extensions header.

6. A special EPS bearer is frequently linked to this QCI.

7. A PDB relevant to a radio interface can be obtained by deducting a 5 ms delayed among a PCEF and the radio base station from the provided PDB.

8. The package delay budget that applies to a radio interface may be calculated by deducting 2 ms from the provided PDB, which represents a delay among a PCEF and the radio base station.

LTE QoS is imposed at the EPS bearer level in 4G. QoS enforcement in 5G occurs at the QoS flow level. EPS bearers, each given an EPS bearer ID, are used in 4G LTE. QoS is implemented in 4G/LTE at the EPS bearer level. Because of the one-to-one mapping, each EPS bearer has a matching EPS Radio Access Bearer (RAB), S1 bearer, and Radio Bearer (RB).

2.3. 5G Systems

The popularity of streaming videos is the main reason for the surge in mobile data use. With several gadgets at their disposal, users are connecting with more and more people. With the emergence of the IoT, networks must be able to support billions of devices. Improved energy economy in mobility devices and networks is becoming more and more necessary as the number of mobile devices and data traffic increases.

Network operators are faced with a difficult situation since they must reduce operating expenses. Users' desire for flat-rate tariffs, which makes them reluctant to pay more for services, increases this pressure. Novel use cases, such those demanding ultra-low latency or great dependability, are made possible by mobile communication technologies, potentially opening up new income streams for carriers.

It is projected that the implementation of 5G would result in a notable improvement in operational efficiency. This aims to deliver complete mobility and coverage while giving spectral efficiency gains, greater data rates, and decreased latency, all of which are equivalent to fixed networks in terms of user experience. In order to support the widespread use of the IoT, 5G must be designed to keep energy consumption, equipment expenses, network deployment and operating costs within reasonable bounds. It must also be able to handle a wide variety of services and applications [5].

Comparing the key characteristics of IMT-2020 (5th generation) with IMT-Advanced (4th generation) according to ITU-R M.2083 is depicted in Figure 2.4.

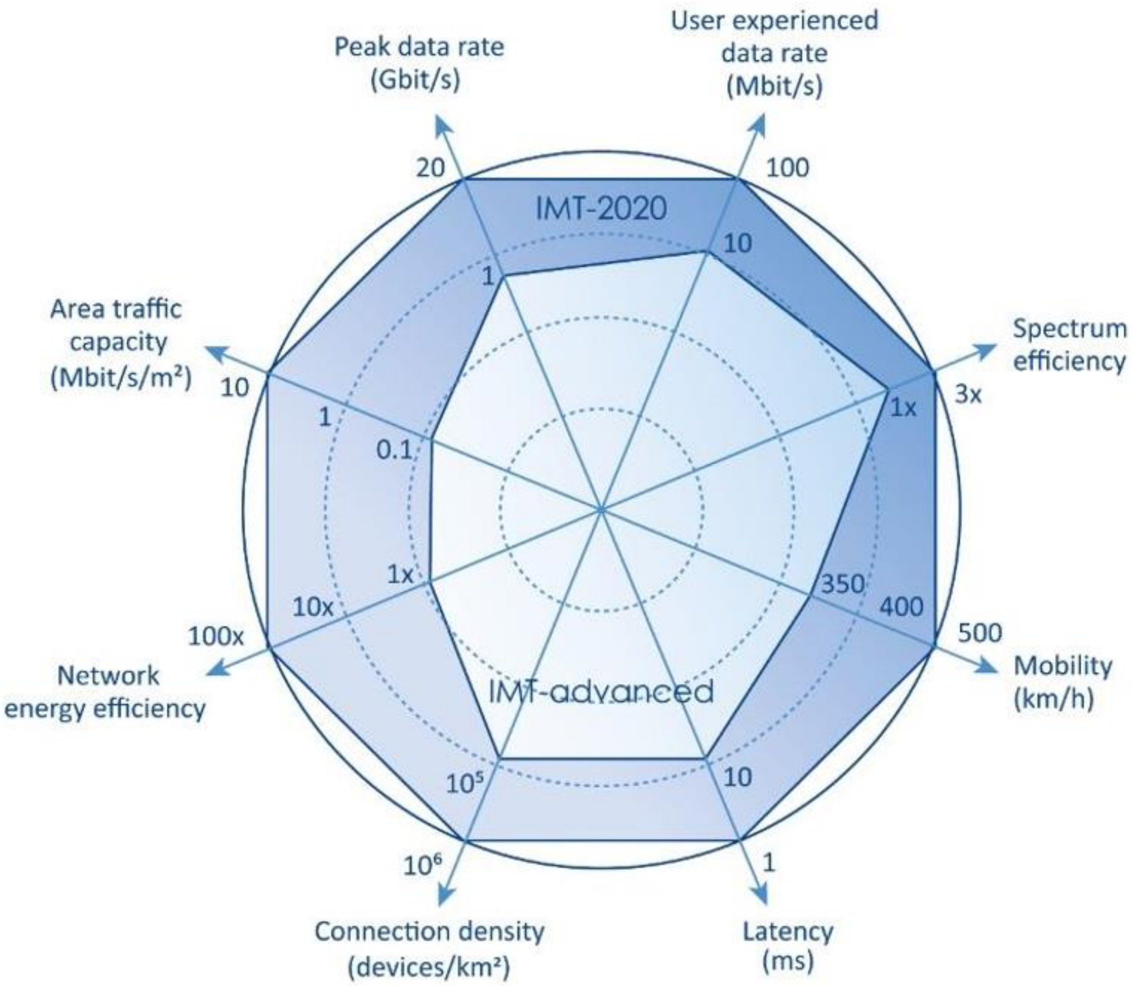


Fig. 2.4. The primary features of IMT-Advanced (4th generation) with IMT-2020 (5th generation) as per ITU-R M.2083

Figure 2.5. illustrates how the potential of 5G presents chances for operators of networks to provide new services to unexplored user groups.

Fig. 2.5. The novel services to previously untapped user segments

The 5G usage cases

The major use cases for IMT for 2020 and beyond have been described in Recommendation by the International Telecommunication Union Radiocommunication Sector. M.2083 ITU-R:

1. eMBB: It provides high capacity for traffic in hotspot scenarios and greatly increases data rates to meet the demands of high user density. It also intends to enable high mobility situations with enhanced user data rates and provide seamless coverage.

2. mMTC: Targeting the IoT, this scenario emphasizes low data rates and low power consumption to support a large number of linked devices.

3. URLLC: As outlined in ITU-R M.2083 and illustrated in Figure 2.6., this scenario is intended to satisfy the needs of mission- and safety-critical applications. As such, it requires a number of essential features.

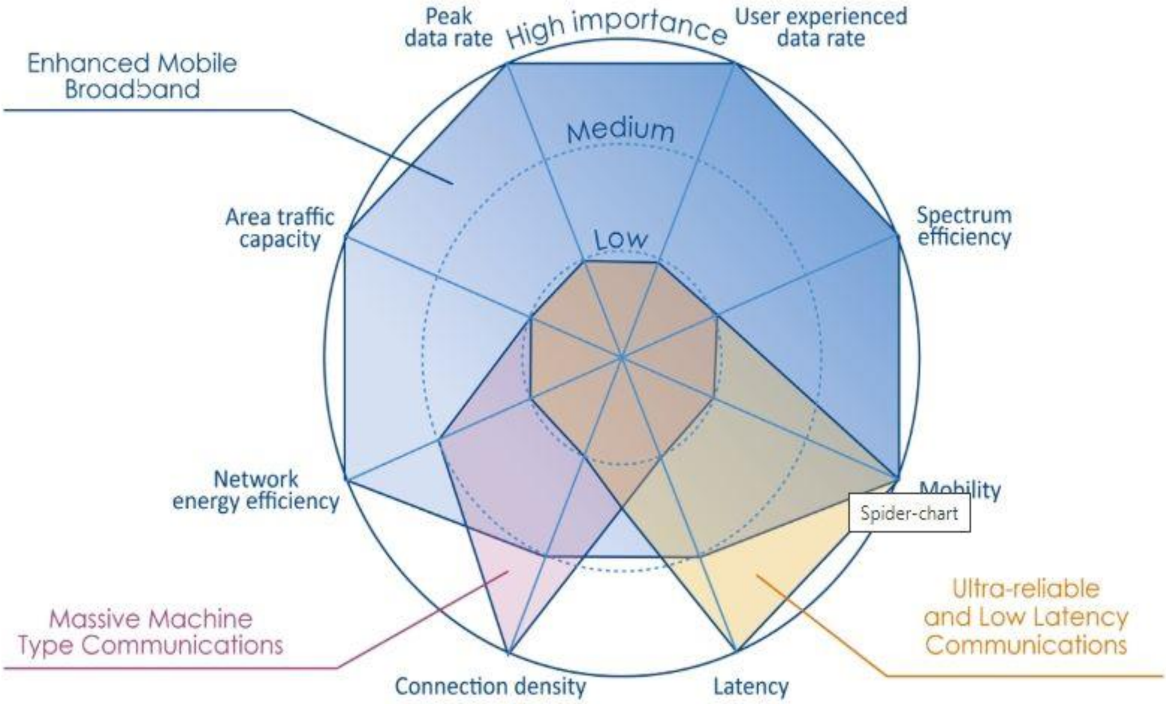


Fig. 2.6. The key application scenarios for International Mobile Telecommunications

In order to describe the next generation of wireless communication networks for 2020 and beyond, the ITU-R has started a project called IMT-2020, as shown in Figure 2.7.

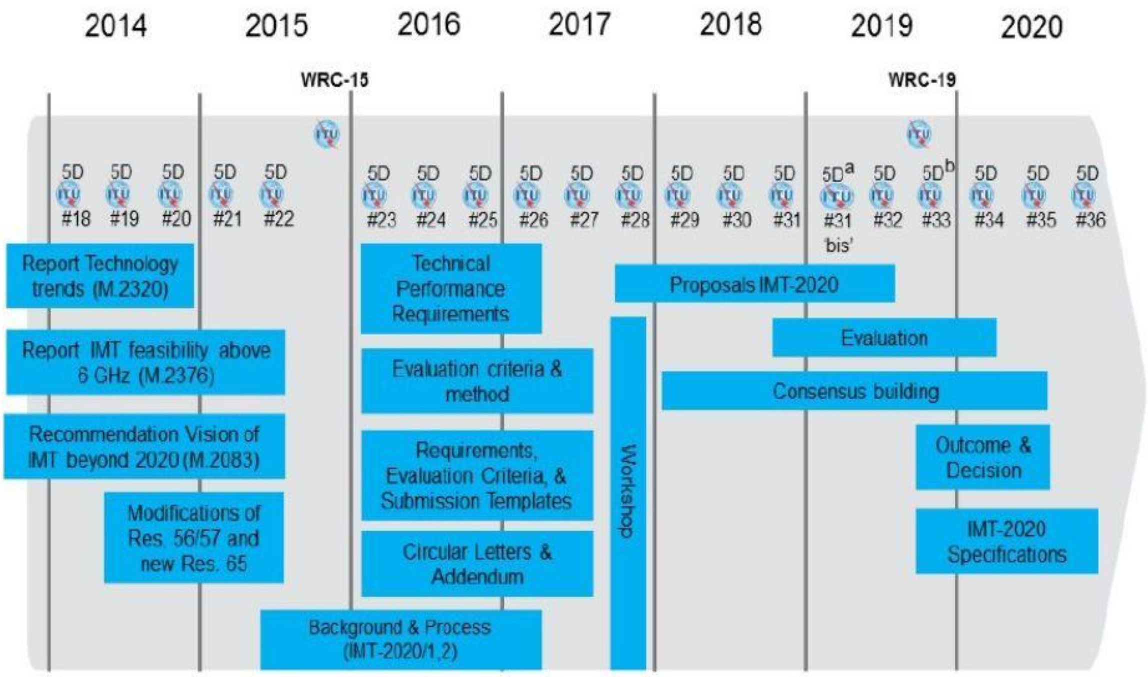


Fig. 2.7. ITU-R's IMT-2020 Project: Shaping the Future of Mobile Communication Networks for 2020 and Beyond

Schedule of events (Taken from Document IMT-2020/2)

The schedule that has been provided relates exclusively to the first call for potential RITs or SRITs. The submission of proposals will decide the calendar for subsequent events.

Beginning with the 28th Working Party 5D meeting, which is set for October 3–11, 2017, proposals may be presented. Submissions for a meeting must be made by 1600 UTC, a full seven days prior to the start of the meeting. Submissions must be completed by 1600 hours UTC, a week before WP 5D's 32nd meeting in July 2019. During this time and going forward, independent evaluation committees will evaluate the suggested RITs and SRITs and will also begin the consensus-building process. For a full depiction of Figure 2.8., see Figure.

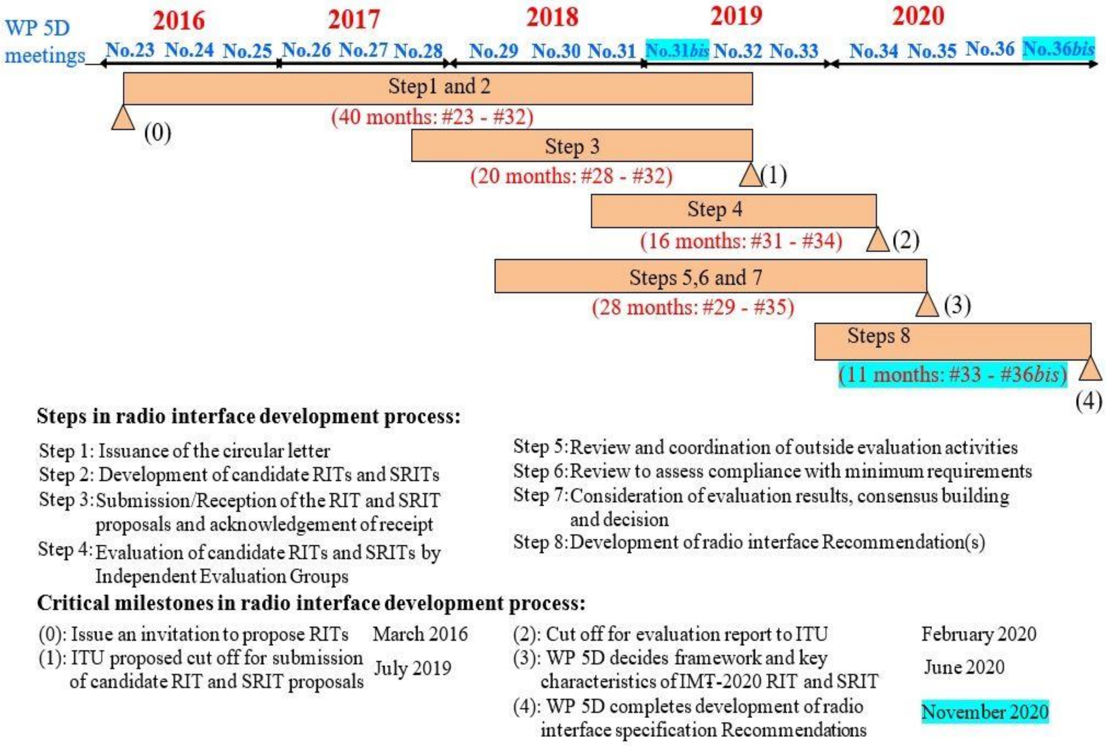


Fig. 2.8. Evaluation and Consensus-Building Process for Proposed RITs and SRITs

Method (Extracted from IMT-2020/2(Rev.2) Document)

ITU-R Resolution 65, "The Principles for the procedure of future IMT development until 2020," lays out the basic standards and guidelines that will be applied when developing the IMT-2020 recommendations and reports. Creating a recommendation or recommendations for a radio interface standard falls under this category.

IMT-2020 is outlined in three usage scenarios according to ITU-R Recommendation M.2083, "the IMT Vision – Framework and overall goals of the future development of IMT beyond 2020." It envisages a wide variety of capabilities for IMT-2020 that are tightly connected to particular use cases and applications. This leads to a wide range of needs. Furthermore, as noted by Recommendation ITU-R M.2083, the relevance and application of IMT-2020 capabilities vary across many use cases and situations, some of which may not be expected at this time. Because IMT-2020 is applicable to a wide range of scenarios, diverse test settings must be taken into account for assessment reasons [6].

Report ITU-R M.2412-0 defines a test environment as the combination of a physical location and a use scenario.

Detailed process

Figure 2.9. provides a visual representation of the step-by-step procedure, which is described in more detail in the paragraphs that follow. While certain activities are carried out inside within ITU-R, others are carried out outside of its purview.

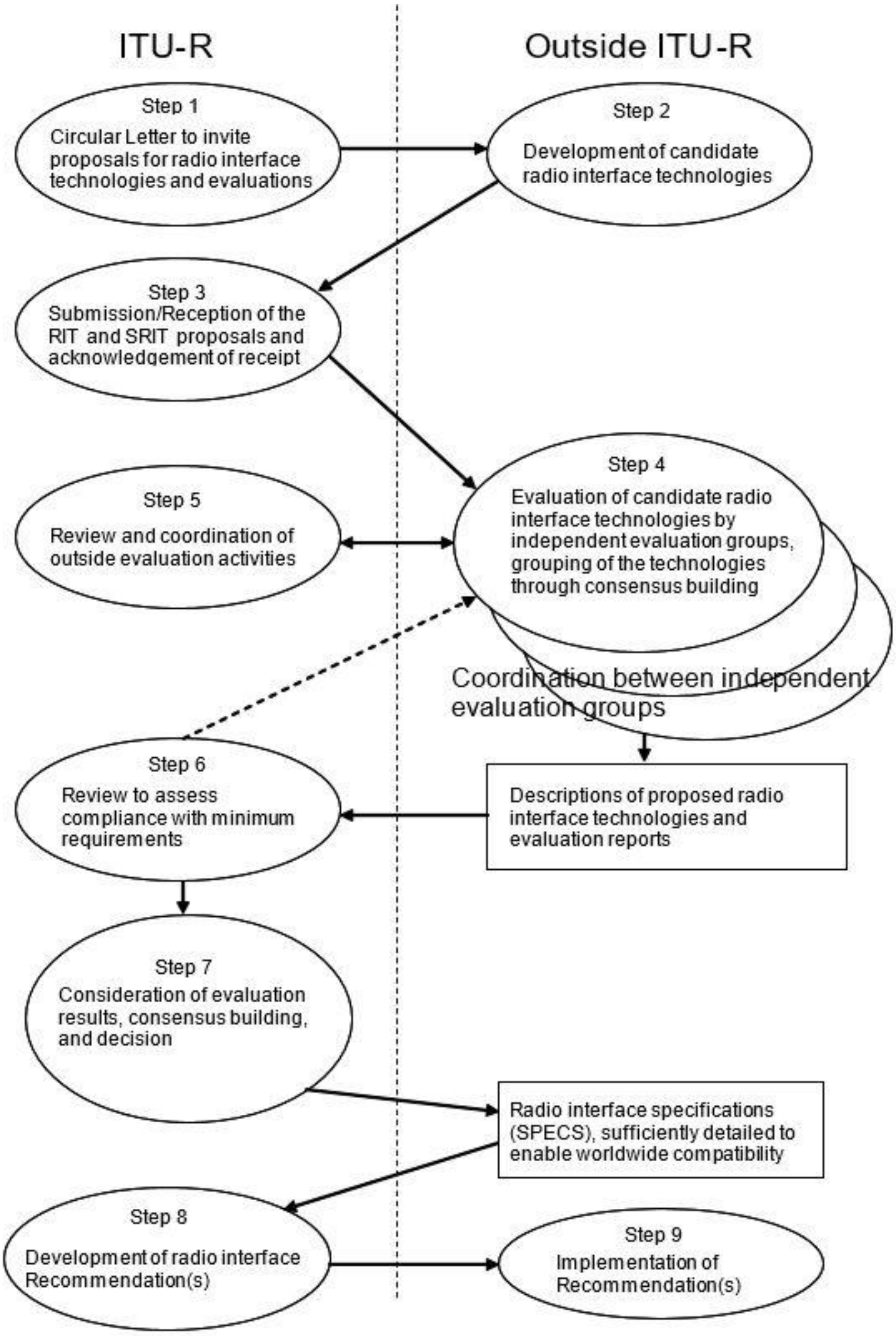


Fig. 2.9. Visual Overview of the Sequential Process: Tasks Beyond ITU-R Scope and Internal Organizational Operations

First step: Request for Proposals for Radio Interface Technology and Assessments.

Circular Letter 5/LCCE/59 states that the Radiocommunication Bureau is inviting suggestions for RITs or SRITs that handle the terrestrial component of IMT-2020. The Circular Letter and accompanying Addenda offer complete information on the submission procedure, including assessment criteria, technical performance requirements, and a template for submitting candidate technology proposals.

Furthermore, welcomed are any further submissions of evaluation studies on the suggested RITs or SRITs, as stated in the Circular Letters and Addenda. These studies, in addition to the first assessment report approved by the proponent, should be supplied by registered independent assessment organizations.

Step 2: Create SRITs or Candidate RITs.

In this phase, which takes place outside of ITU-R, potential terrestrial components RITs or SRITs are created to satisfy IMT-2020's minimal technical performance standards and assessment standards, as stated in Resolutions ITU-R 65, Section 6 g), and detailed in Reports ITU-R M.2411-0. For RITs or SRITs to be taken into consideration, there must be a minimum of three test environments—two under the eMBB along with one under mMTC or the URLLC for RITs, and a minimum of four under SRITs-that cover each of the three usage scenarios.

Step 3: Send in and accept your SRIT and RIT proposals.

Member States, Sector Members, Associates of ITU R Study Group 5, and other organizations adhering to Resolution ITU-R 9-5 are among the entities qualified to propose RITs or SRITs. Completed template from Reports ITU-R M.2411-0 and any pertinent extra inputs are required for each submission. The proposal's proponent should adhere to ITU's intellectual property policy and indicate the version of the IMT-2020 technical criteria the proposal is meant for.

Technical data about potential RITs and SRITs has been received, and the Radiocommunication Bureau has acknowledged receipt of it.

Step 4: Independent Groups Evaluate.

Candidates for RITs or SRITs are invited to be evaluated by independent assessment committees, which may include ITU-R members, standards bodies, and other interested parties. As directed by Report ITU-R M.2411-0, these organizations must register with ITU-

R and submit the assessment results. To guarantee consistency in the outcomes, coordination between these groups is recommended.

Step 5: Examine and Organize External Assessment Activities.

As the liaison between independent assessment groups, WP 5D tracks developments and resolves conflicts to promote consensus-building.

Evaluation of Compliance with Minimum Requirements is the sixth step.

Proposals are evaluated by WP 5D to see if they meet the evaluation criteria and minimal technical performance standards. All eligible RITs and SRITs move on to Step 7.

Step 7: Evaluate the findings, get a consensus, and make a decision.

In order to achieve industry support and worldwide harmonization, WP 5D takes evaluation results into account. RITs may be reorganized or modified to better coincide with the goals of IMT-2020.

Step 8: Create the recommended radio interface (s).

ITU-R creates the IMT-2020 terrestrial components radio interface recommendation(s) based on Step 7 results to guarantee global compatibility.

Step 9: Put the recommendation(s) into practice.

The creation of further standards, the development of equipment, testing, trials in the field, type approval, commerical aspects, and the implementation of the IMT-2020 infrastructures leading to commercial services are examples of external activities.

Using SP-150149, 3GPP developed a timeline for its contribution to the fifth generation of mobile phone networks at TSG #67 in March 2015.

In September 2015, 3GPP held a seminar in Phoenix, USA, at RAN #69, to share the priorities and viewpoints of participating firms on next-generation radio technology, as well as to provide information about ITU-R IMT-2020 plans. According to the chairman's summary (RWS-150073), there are three processes involved:

1. The process of getting ready for high-frequency band channel modeling work.

2. Studying the creation of needs and scenarios for radio technologies of the next generation.

3. Research to evaluate technical options for next-generation radio technology for RAN working groups.

The Rel-14 research "The channel Models Investigation for the Spectrum Above 6 GHz" (FS_6GH_CH_model, RP-160210) was started at RAN #69 in September 2015 by 3GPP. In June 2016, this research came to an end at RAN #72 with the issuance of the 3GPP TR 38.900.

In order to determine common deployment cases and develop particular requirements for next-generation access technologies, taking into account the needs of IMT-2020, 3GPP started executing the Rel-14 task (FS_NG_SReq, the RP-160811) "The Investigation of The scenarios and Requirements for The next-generation Access Technologies" at RAN #70 in December 2015. 3GPP TR 38.913, which outlines scenarios, important performance criteria, architecture, migration, innovative services, operation, and testing requirements, was used to help bring this research to a close at RAN #74 in December 2016 [7].

ITU-R suggested potential radio interface solutions for IMT-2020 in a circular communication dated March 2016. ITU-R M.2410 outlines the requirements for IMT-2020, which include:

– minimum spectral efficiency;

– users plane latency (a single user, small packets of data) for eMBB and URLLC;

– the control plane latency (idle mode => active): 10–20 ms. These are the general goals for IMT-2020.

Additional specifications included eMBB mobility in rural regions and a maximum total system bandwidth.

The Rel-14 study "The investigation of NR Access Technology" (FS_NR_newRAT, RP-170379) was started by 3GPP at RAN #71 in March 2016 with the goal of identifying and developing technological components for a variety of use-case scenarios (such as enhanced wireless broadband, massive MTC, and critical MTC) and the further requirements outlined in 3GPP TR 38.913. Following the release of The rel-14 3GPP TR 38.912, this research came to an end at the RAN #75 on March 17. It looked into the viability and capabilities of NR accessing technologies and presented a number of characteristics for them.

3GPP started work item the rel-15 (NR_newRAT, RP-181726) on " NR Access Technology" on March 17 at RAN #75. This WI was eventually split into three parts to accommodate various network operator requirements:

1. "Early Release Rel-15": Emphasis on buildings variant 3, also known as Standalone NR (NSA NR), which is the introduction of NR base stations with an evolved packets core (EPC) to the Advanced LTE LTE system ; functional freeze: the 17th of December; ASN.1 freeze: March 18. This is the initial phase of the migration.

2. "Normal Freeze Rel-15": This refers to Standalone NR architecture version 2, which focuses on NR base stations without LTE linked to the 5G core network (5GC); functional freeze: June 18; the ASN.1 frozen on September 18.

3. "Late Release Version 15": NR-NR dual connectivity, architecture variants 4 and 7 (which are comparable to the addition of an LTE base station and an LTE base station to a SA the NR network, respectively), and functional and ASN.1 freeze dates of December 18 and March 19, respectively.

The 3GPP proposal ("5G") for IMT-2020 contains two representations as LTE-Advanced can satisfy certain of the requirements for IMT-2020 in specific use cases:

1. Radio Interface Technology Set: that include standalone LTE, NB-IoT, eMTC, and LTE-NR Dual Connectivity; NR RIT component + E-UTRA/LTE RIT component.

2. Radio Interface Technology Non-Radio.

2.4. Completion Date of the 5G Standard

There were several difficulties in developing and completing the 5G standard, also called Rel-15. Remarkably, in September 2018, the non-backward compatible request for changes for NSA NR remained active. ASN.1 integration into a frozen specifications turned out to be a challenging process that called for well-written change requests, particularly when there were short notice deadlines. The requirement for reliable pre-work from other Working Groups made it difficult for some WGs, such the RAN4 for the RF/RRM and the RAN5 for Testing, to stay on schedule.

Notwithstanding these difficulties, 3GPP completed its tasks within the IMT-2020 deadline:

– the NR RIT and NR+LTE SRIT were first presented in January 2018 through PCG40_11.

– the characteristics of the NR RIT and NR+LTE SRIT, as well as the preliminaries of the self-evaluation, connect budget results, and compliance templates, were shared in September/October 2018 through PCG41_08.

– in June 2019, the 3GPP submitted 5G candidate data for NR RIT and NR+LTE SRIT through PCG43_07, including the characteristics, compliance and the amount of link budget templates, as well as the 3GPP self-evaluation TR 37.910 (which included additional the rel-16 enhancements) to step 3 of the IMT-2020 process. It's crucial to remember that the features templates provided a thorough rundown of the technology under consideration.

– the final 3GPP standard overviews were presented in June 2020 using the PCG45_07 for NR+LTE SRIT and the PCG45_08 for NR RIT. The final 2020-06 specification sets (Relese 15 & 16) were made available in July 2020 to facilitate the translation of the the 3GPP OPs. Characteristic templates with an overview of the technology under consideration are shown in Figure 2.10.

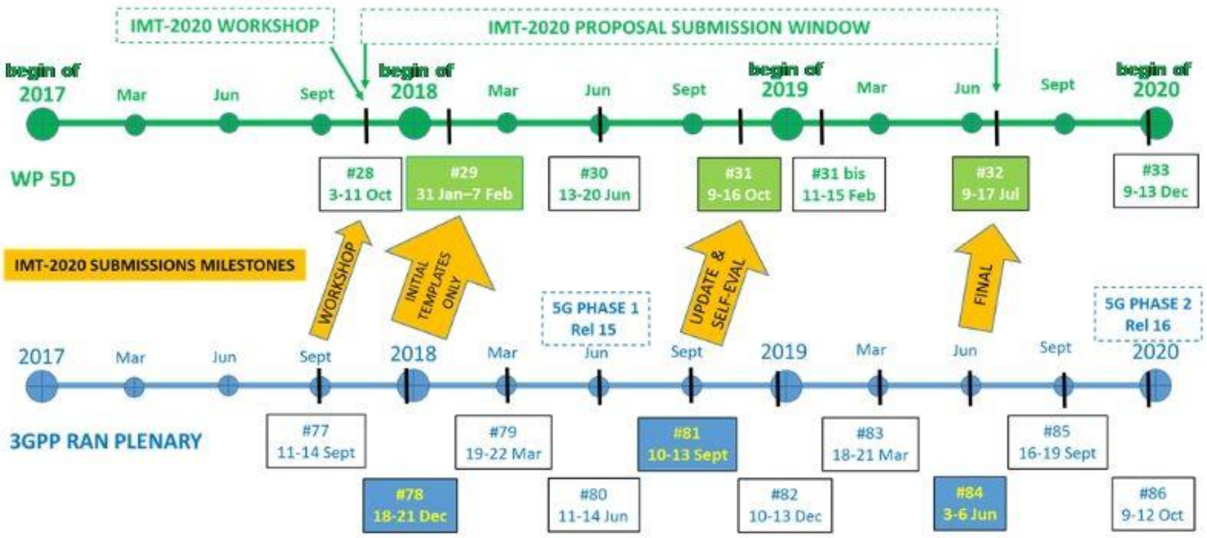


Fig. 2.10. Characteristics templates with overview about considered technology

Additional Advancements in 5G Technology

Numerous NR enhancements have been investigated in relation to Release 16. These include of improving MIMO for NR, supporting NR positioning, integrating 5G V2X with NR sidelink, and evolving eNB(s) design for both E-UTRAN and NG-RAN. NR-based access to unlicensed spectrum, the implementation of a two-step Random Access Channel for NR, the management of cross-link and distant interference in NR, and the improvement of Layer 1 for NR URLLC are additional factors to be considered.

In addition, efforts have been focused on improving mobility for NR, UE power savings in NR, and multi-RAT Dual-Connectivity and the carrier Aggregation improvements for both LTE and NR. Singular radio call continuity from 5G to 3G, fully integrated access and backhaul for NR, and UE radio capabilities signaling improvements for NR and E-UTRA features have also been investigated.

Supporting NR in the IoT, enabling NG-RAN support for private networks, and utilizing the NG interface for Wireless Wireline Convergence are all included in the scope. Radio frequency requirements have received special attention, with the addition of NR RF requirements for frequency range 2 and support for NR Downlink 256QAM.

Aspects such as RRM requirements for Channel State Information Reference Signal based Layer 3 measurement in Network Reliability and Self-Organizing Networks and Minimization of Drive Tests support are also taken into account. High-speed train scenarios are addressed in NR support, and NR RRM is improved. Furthermore considered have been the shift in Iuant interface requirements from the 25-series to the 37-series, the direct data forwarding for inter-system mobility between NG-RAN and E-UTRAN nodes, and the addition of capabilities set(s) to multi-standard radio specifications [7].

Recall that in June, Release 16's stage 3 and the ASN.1 freeze took place.

Rel-17 took into account, for example, the subsequent NR enhancements:

1. A number of NR innovations have been investigated for Release 17, including as the use of NR Dynamic Spectrum Sharing, improvement in NR Sidelink capabilities, and advances in MIMO technology. Strengthening support for the Enhanced Industrial IoT and guaranteeing ultra-reliable and minimal latency communication for NR have also received attention.

2. Developments have been made to provide NR solutions with power-saving characteristics for UE in NR, as well as solutions that can smoothly connect with non-terrestrial networks. Multicast and broadcast services, improvements to Integrated Access and Backhaul, and support for modest data transfers in the INACTIVE state of NR are additional factors to consider.

3. As 5G develops, special needs from different situations – like high speeds train situations in both frequency bands (FR1 and FR2) – must also be taken into consideration. The current advances include positioning improvements, coverage improvements, and further modifications of NR RF needs for various frequency bands.

4. Technical improvements taken into consideration include the addition of the bandwidth selection set 4 for NR, NR repeaters, support for reduced capacity NR devices, and the introduction of DL 1024the QAM for NR FR1. Improvements in Radio Access Network (RAN) slicing for NR, Uplink Data Compression, and Sidelink Relay for NR are some of the components that include the overall breadth of improvements.

5. In addition, a major emphasis has been on QoE management and optimizations, guaranteeing that a range of services profit from the developing 5G capabilities. The commitment to improving 5G technology is demonstrated by the inclusion of UE high power classes (1.5 and 2) for different bands and Carrier Aggregation combinations, as well as the introduction of Total Radiated Power and Total Radiated Sensitivity standards and test techniques.

Although a lot of improvements for Release 18 were authorized in December 2021, before starting work on Release 18, the Working Groups will focus on finishing Release 17. December 2023 is when Releases 18 Stage 3 will be frozen, and March 2024 is when ASN.1 will be frozen in tandem.

The constant improvements in 5G are motivated by the constantly shifting demands of the industry and consumers, much as the evolutionary routes of GERAN, UMTS, and LTE in the past. In order to satisfy new needs and maintain leadership in telecom innovation, 5G technology must continue to advance.

2.5. 5G Network Architecture

Service Based Architecture is included into the 5G network's architecture. Basically, the 5G network divides the original architecture into several independent parts that each fulfill certain roles, making it a user-centric, highly intelligent, and elastic network. Now, let's explore the 5G network's details. CU, DU, and AAU are the three components that we will first look at. DU is responsible for managing physical and business needs in real time, whereas AAU includes RRU, passive wireless, and part of the BBU physical layer. CU is in charge of managing non-real-time services. Figure 2.11. shows what the 5G network's architectural design looks like.

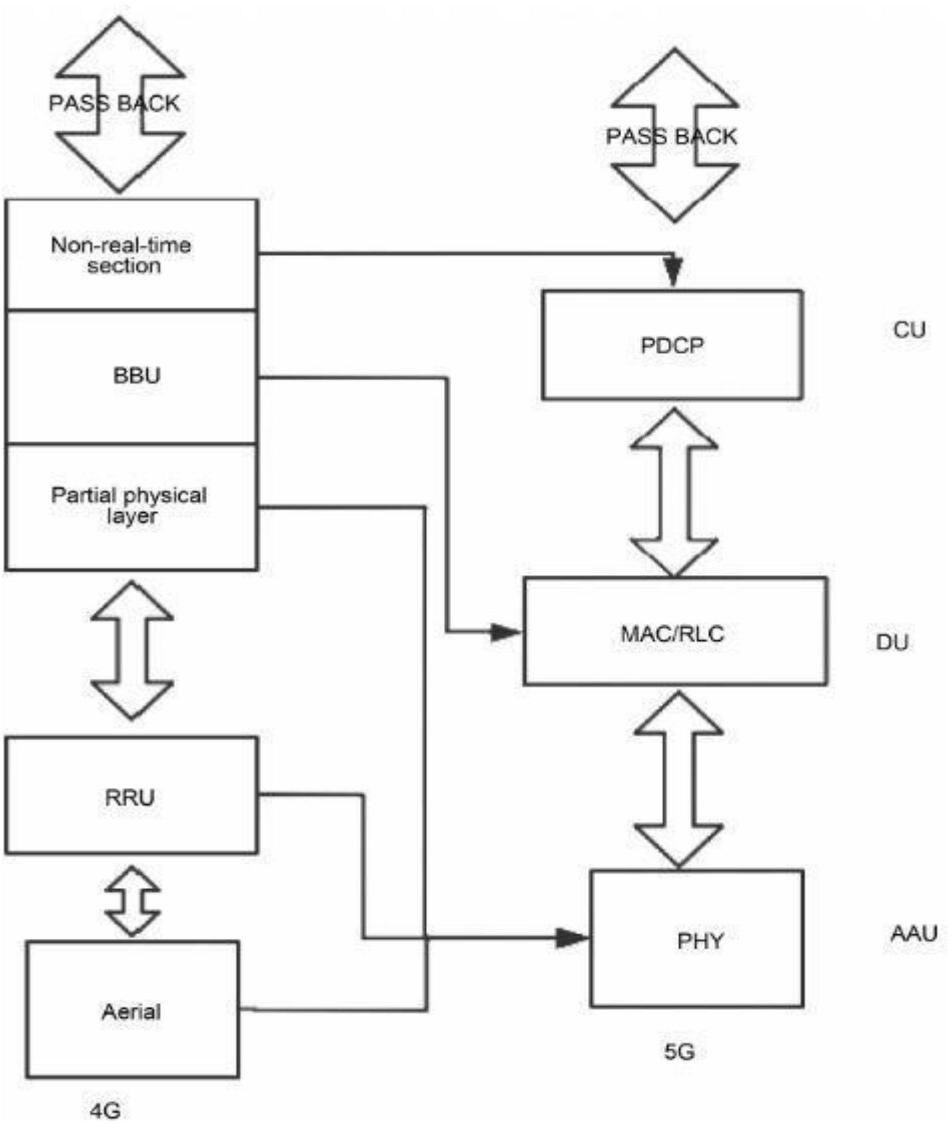


Fig. 2.11. 5G unlimited network architecture

Challenges with Mobile Network Hardware

An experiment's hardware components are its foundation. Hardware equipment in mobile communications systems includes RF front-end devices, frequency converter, and baseband DPUs. The 5G network uses a more sophisticated operating mode to obtain more storage capacity and lower latency, which creates substantial problems in chip production. For example, GaN material is required by chips to support the a high-frequency band of power amplifier above 4 GHz, but it is costly and difficult to manufacture. As such, more work has to be done to solve hardware-related issues. Table 2.3. outlines the distinctions among 4G and 5G.

Table 2.3

Performance comprasion

	4G	**5G**
Time delay	10 ms	Smaller than 1 ms
Number of mobile links	Eight billion	Eleven billion
Channel broadband	20 MHz 200 MHz	100 MHz (lower than 6 GHz) 400 MHz (lower than 6 GHz)
Frequency band	600 MHz to 5.925 GHz	600 MHz (millimeter wave)
Date low	7.2 Eb/month	50 eb/month
Peak data rate	1 Gb/s	20 Gb/s
Available channel	3GHz	30 GHz
Link density	One million links/km^2	One million links/km^2
Uplink waveform	Use SC-FDMA	Use CP-OFDM

QoS enforcement occurs in the QoS flow level in 5G NR. Using the QoS Flow Identifier, each QoS flow packet is categorized and identified. Whereas in 4G mapping is a one-to-one process between EPC and Radio Bearers, in 5G QoS flows, mapping is done in the Access Network to DRBs. 5G supports a new delayed critical GBR in addition to non-GBR and GBR flows, much like 4G LTE did. Reflective QoS is another novel idea brought forward by 5G. The three following QoS flow types are supported by 5G QoS architecture:

- GBR QoS flow, which needs a guaranteed flow bit rate.
- Non-GBR Quality of Service flow that doesn't need a GBR of flow.
- The delay Critical QoS flow, For Mission Critical assured flow bit rate.

Table 2.4 illustrates the variations in QoS parameter compilation between 5G and 4G.

Table 2.4

5G and 4G QoS Parameters Comprasion

Parameter	**5G**	**4G**
QoS Identifier	5G QI (QoS Identifier)	QCI (QoS Class Identifier)
IP Data Flow (UE to UPF/PGW)	QoS Flow	EPC Bearer
Flow/Bearer Identifier	QFI (QoS Flow QoS Identifier)	EBI (EPS Bearer ID)
Reflective QoS	RQI (Reflective QoS ID)	Not Applicable
Data Session	PDU Session	PDN Connection

Policy and pricing are implemented in the QoS flow, which is the 5G system's lowest degree of granularity. If several SDFs have the same policy and pricing rules, they can be carried in the same QoS flow (much like an EPS bearer in 4G LTE). Within a single QoS flow, every traffic is treated equally.

The 5QI has many standard values. Figure 2.12. from the 3GPP TS 23.501 shows how to translate 5QI features to QoS attributes.

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Services
1	GBR	20	100 ms	10^{-3}	N/A	2000 ms	Conversational Voice
2		40	150 ms	10^{-3}	N/A	2000 ms	Conversational Video (Live Streaming)
3		30	50 ms	10^{-3}	N/A	2000 ms	Real Time Gaming, V2X messages Electricity distribution – medium voltage, Process automation monitoring
4		50	300 ms	10^{-6}	N/A	2000 ms	Non-Conversational Video (Buffered Streaming)
65		7	75 ms	10^{-3}	N/A	2000 ms	Mission Critical user plane Push To Talk voice (e.g. MCPTT)
66		20	100 ms	10^{-2}	N/A	2000 ms	Non-Mission-Critical user plane Push To Talk voice
67		15	100 ms	10^{-3}	N/A	2000 ms	Mission Critical Video user plane
75							reserved for future use
71		56	150 ms	10^{-6}	N/A	2000 ms	"Live" Uplink Streaming
72		56	300 ms	10^{-4}	N/A	2000 ms	"Live" Uplink Streaming
73		56	300 ms	10^{-8}	N/A	2000 ms	"Live" Uplink Streaming
74		56	500 ms	10^{-8}	N/A	2000 ms	"Live" Uplink Streaming
76		56	500 ms	10^{-4}	N/A	2000 ms	"Live" Uplink Streaming
5	Non-GBR	10	100 ms	10^{-6}	N/A	N/A	IMS Signalling
6		60	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		70	100 ms	10^{-3}	N/A	N/A	Voice, Video (Live Streaming), Interactive Gaming
8		80	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming), TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		90					
69		5	60 ms	10^{-6}	N/A	N/A	Mission Critical delay sensitive signalling (e.g. MC-PTT signalling)
70		55	200 ms	10^{-6}	N/A	N/A	Mission Critical Data (e.g. example services are the same as 5QI 6/8/9)
79		65	50 ms	10^{-2}	N/A	N/A	V2X messages
80		68	10 ms	10^{-6}	N/A	N/A	Low Latency eMBB applications Augmented Reality
10		90	832ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.) and any service that can be used over satellite access type with these characteristics
82	Delay-critical GBR	19	10 ms	10^{-4}	255 bytes	2000 ms	Discrete Automation
83		22	10 ms	10^{-4}	1354 bytes	2000 ms	Discrete Automation, V2X messages, Advanced Driving: Cooperative Lane Change with low LoA.
84		24	30 m	10^{-5}	1354 bytes	2000 ms	Intelligent transport systems
85		21	5 ms	10^{-5}	255 bytes	2000 ms	Electricity Distribution- high voltage. V2X messages (Remote Driving)
86		18	5 ms	10^{-4}	1354 bytes	2000 ms	V2X messages (Advanced Driving: Collision Avoidance, Platooning with high LoA.

Fig. 2.12. The mapping from 5QI to QoS characteristics

5G NR QoS Configurations: The next set of 5G QoS Parameters were established in the context of QoS Implementation in 3GPP standard 23.501.

The 5G QoS Identifier is a unique identifier for QoS attributes that impact many aspects of the connection layer protocol configuration, admission thresholds, scheduling weights, and queue management thresholds.

Allocation and Retention Priority: Provides details on the priority level, pre-emption vulnerability (may be preempted by other QoS flows), and pre-emption capability (may preempt resources allotted to other QoS flows).

Optional parameter: Reflective QoS Attribute. This flow may include some traffic that uses reflective QoS.

Measured throughout the Averaging Time Window is the Guaranteed Flow Bit Rate, or GFBR. The lowest possible bit rate in which the service can continue to function is advised.

The maximum bitrate that this QoS flow is intended to support is set by the MFBR.

Session-AMBR is the total max bit rate for each PDU session across all of its QoS flows. Each UE has UE-AMBR.

QoS Notification Control: Sets up NG-RAN to alert SMF in the event that GFBR is not fulfilled. beneficial if the program can adjust to changing circumstances. If different QoS profiles are set up, NG-RAN shows if one of them fits the performance metrics that are now being satisfied.

Maximum Packet Loss Rate: Only voice media are affected by this as of Release 16.

Thus, the criteria for QoS in 5G networks are covered in this subsection. on order to fulfill the demands of many applications and services on the 5G network and to provide the best possible communication quality, QoS criteria have been established.

Throughput is the primary QoS metric. The greatest quantity of data that a network can send in each length of time is determined by its throughput. 5G networks must have high throughput to facilitate the rapid transfer of massive amounts of data, particularly for demanding applications like virtual reality, streaming services, high-quality video, and others.

Latency is the second QoS parameter. The amount of time needed for data to travel between the sender to the recipient is referred to as latency. In order to guarantee prompt response and provide real-time features for interactive applications like audio and video conferencing, multiplayer gaming, and more, 5G networks must have low latency.

Real-time support is the third QoS parameter. Certain services and applications, such automated systems, medical services, and industrial operations, need constant, fast communication. For these kinds of crucial applications, 5G networks must offer real-time support to deliver low latency and high dependability.

Mobility is the fourth QoS parameter. 5G networks should be able to maintain connectivity even when users move between multiple base stations and frequency bands thanks to new procedures. This is especially crucial for mobile applications, like IoT devices, as these gadgets could go about.

Finally, communication continuity is the sixth QoS parameter. It is necessary for 5G networks to maintain a steady and unbroken connection even in the face of obstructions, device mobility, and changes in communication circumstances. For users and apps, this guarantees consistent availability and dependable communication.

Different kinds of apps and services are used to establish the QoS specifications for 5G networks. Having a thorough understanding of these specifications' aids in the creation of efficient procedures for 5G mobile network management and quality assurance.

Figure 2.13. illustrates the eight specification requirements that drive 5G technology.

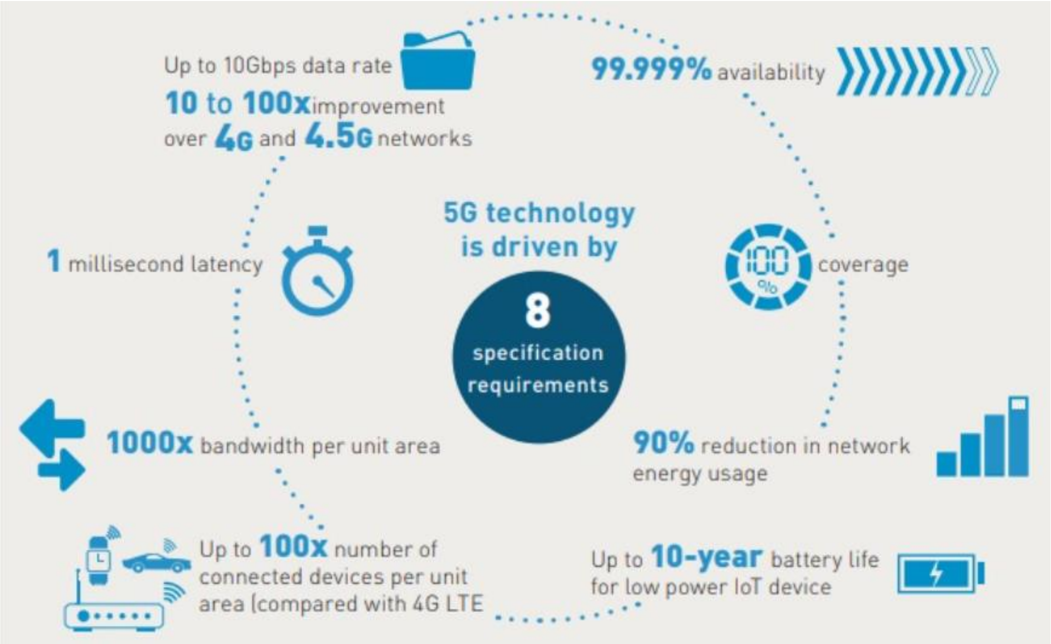


Fig. 2.13. The 8 specification requirements of 5G technology

The 8 specification requirements of 5G technology, which can see in the Figure 2.13.:

– 10 to 100 times faster than 4G and 4.5G networks, with a data throughput of up to 10Gbps;

– only a millisecond delay;

– a bandwidth of 1000 times per unit area;

– availability of 99.999%; up to 100x greater number of connected gadgets per unit area than 4G LTE;

– complete coverage of 100%;

– 90% less energy is used by the network;

– a low-power IoT gadget may have a 10-year battery life.

Firstly, compared to earlier generations of mobile networks, 5G technologies offer substantially larger bandwidth due to their fast data transfer speeds. This is particularly crucial when considering the growing amount of data being transferred over the network for things like virtual reality, high-definition music, streaming videos, and more.

Low latency is the second key component of 5G technology. The term "latency" describes the amount of time a signal takes to go from the originator to the recipient. Applications like driverless cars, real-time multimedia services, remote industrial process management, and various other interactive applications can be accomplished by lowering latency in 5G networks.

Another crucial aspect of 5G technology is network capacity. It establishes the maximum number of concurrently operating devices in the network with excellent service quality. Compared to earlier generations, 5G networks have a much larger capacity, which enables more gadgets to have been connected to the network at once and guarantees reliable connection for each of them.

One of the most important specifications for 5G networks is scalability. The term "scalability" describes a network's capacity to function effectively as the quantity of data sent and the number of connected devices rise. This necessity informed the construction of 5G technologies, which provide reliable communication even in situations when network demand is significant.

Finally, achieving great communication dependability is the goal of 5G technology. Applications that depend on constant communication, such vital medical services, autonomously unmanned systems, and other crucial applications, should pay special attention to this. 5G networks are equipped with systems that provide a dependable connection and communication recovery in the event of a loss.

A comprehensive examination of the specifications for 5G technologies aids in comprehending the essential elements that must be taken into account for the management and quality assurance of mobile networks that employ these technologies. The gathered network data may be utilized to evaluate and examine the network's adherence to the specified 5G specifications.

Therefore, based on the information given, 10 Gbps data transmission speeds, 1 millisecond latency, high network capacity, an increase in the amount of devices that are connected, a high availability, a full network coverage, a 90% energy consumption reduction, and a battery life of as long as ten years for a low-power IoT devices are among the main requirements of 5G technologies. These specifications, which outline the features of 5G technologies, are crucial for the administration and quality assurance of mobile networks that employ these technologies.

CONCLUSION TO CHAPTER 2

There are major differences between LTE and 5G networks in terms of design, protocols, and capabilities.

The EPS architecture, which comprises the EPC (short network component) and E-UTRAN (radio interface), provides the foundation for 4G. Primary components: PCRF, HSS, SGW, PGW, and MME. Peak 4G speeds reach up to 1 Gbps.

eMBB, mMTC, and URLLC are only a few of the many use cases for which 5G was designed. Its distributed core is part of a revolutionary modular design. Up to 10–20 Gbps of speed, extremely low latency, excellent dependability, and connection density are all possible with 5G.

Key differences between 5G and 4G:

- utilizing massive MIMO and millimetre waves;
- supporting network slicing and many usage scenarios inside a single network;
- one benefit is that movement at 500 km/h is possible;

– one millisecond is the maximum latency on the radio interface, while one million devices per km2 is the maximum density of connections.

As a result, 5G drastically increases the potential of mobile communication, laying the groundwork for the digital revolution in both the business and society. One of the primary goals of the telecom sector is still the advancement of 5G technology.

CHAPTER 3
DATA COMPRESSION TECHNIQUES FOR EFFICIENT MOBILE NETWORK MONITORING

3.1. Evaluating a Quality of Monitoring Solution for Mobile Network M-Plane Data

On cellular networks, a large amount of MPlane data is duplicated or departs very little from the original and hence does not communicate any meaningful information. Large amounts of the overall M-Plane data are produced by several ancillary Nes, those are not crucial yet produce the least valuable data. Furthermore, not redundant information pertaining to the most significant Nes should be gathered and stored in current NMS systems [22], [23]. The network operator may choose that Nes to employ for M-Plane data gathering by using the QoM solution's defining classes. Said another way, the QoM classes specify the maximum amount of loss of information that a given M-Plane data may tolerate before crucial information is lost and cannot be recovered at the point of reception.

There are two methods for defining QoM classes in practice: Network operators establish the acceptable information loss limitations for the QoM class by applying their past understanding of NT indicators to define the QoM class. 2: A driven by data QoM class that uses a data-driven approach to set information loss bounds for a QoM class in DF. In order to determine these restrictions, our technique gathers and utilizes the data entering the DF as the training set. It should be noted that the total number of QoM classifications has no known practical limit.

However, in our investigation, we employ three QoM classes: Because it contains the least amount of data deletion, the precision of this class is the one that most closely matches ideal M-Plane data gathering and storage. Before being sent during compression, superfluous Danix values are eliminated in this class. By decompressing the data, the precise sequence of data may be retrieved, guaranteeing that no information is lost. This class is appropriate for radio accessing network elements such important sites, elements close to premium clients, and fundamental NEs like the service provider gateways and the mobile management entity.

Class Normal: In this class, all subsequent M-Plane values of data that differ by a small value δ are removed so that $| X[i] - X[m] | \leq \delta << Xb$, where X[i] is current data point, X[m] is the last data point that has been recorded, and Xb is the median of the data sequence X. This results in a minimal loss of information. See how a single amount of information, or the partial constant, roughly corresponds to the values of datax that have been erased. Information values that are too similar to the most recent data point collected are eliminated prior to data transfer. Therefore, with little information lost, decompression of this type of compressed data yields essentially identical data series. These classes of NEs are useful for network operators to keep an eye on the less important ones, such pico, mini, and femtocells.

$X[i]-X[m] | \leq \delta 0$ \\ Xb, where $\delta < \delta 0$, X[i] is current data the point, X[m] is the previous data record point, and Xb is the median of the data points in sequence X. The Sharp Class is accountable for the slight information loss that results from deleting all subsequent M-Plane values of data that differ by a small value δ 0. After eliminating any datax values smaller than δ 0 from the most recent recorded data point, this category corresponds to the last recorded data point by a single value.

Decompressing this type of compressed data yields data series that are comparable with minimal information loss. At least crucial places, this class may be used to keep an eye on supplementary NEs in a network, like picocells, femtocells, and gNBs. A collection of components is used to implement the QoM classes suggested by the QoM concept for differentiated monitoring and M-Plane data compression.

In a wireless network design, these components can be deployed in either a core cloud system or the mobile cloud edge based on their intended uses and requirements for computational power. We carry out an experiment to assess the QoM solution in this part. As a result, the initial step will be to describe how the QoM system is implemented and configured. After that, we assess the experiment's findings. 1. Configure the test We test the suggested QoM idea using two private cloud settings that Nokia kindly supplied for our study. As Figure 3. demonstrates that although OpenStack is used in the other environment, one is built into the HP Matrix cloud [24, 25]. Different components of the QoM system are executed on separate virtual machines within these two clouds. Figure 3.1. depicts the experiment's overall layout.

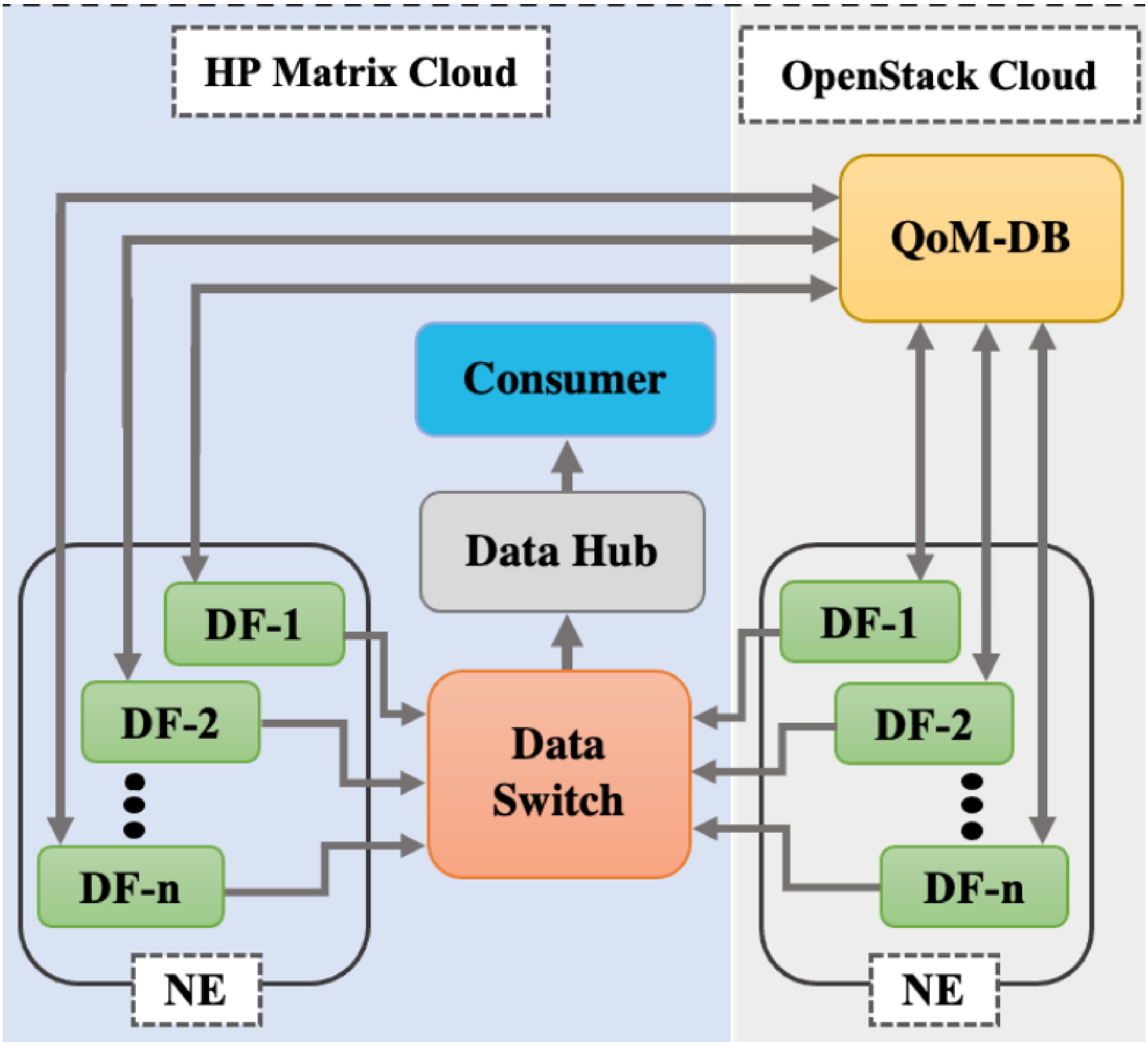


Fig. 3.1. General scheme of the experiment

Although they are frequently seen in OpenStack and HP Matrix cloud settings, data collectors operate independently on distinct virtual machines. Every virtual machine is equipped with a 2.4GHz dual-core CPU, 1GB of RAM, and the Ubuntu operating system. During setup, we implemented 25 DFs; 12 of them are currently operating on the HP Matrix cloud, while the remaining 13 are running on the OpenStack cloud. Every DF replicates live M-Plane LTE cell data from the actual network. Information is gathered and sent to DF. We sent data using the Kafka Producer API, the Java programming language, and a Python script to accomplish Fetching. Next, we used Python and JDK interpreter to test DF on a Linux environment.

Apache Kafka ZooKeeper and Broker are part of the DS suite. In the HP Matrix cloud, which we created up using Apache Kafka, Kafka Broker and ZooKeeper operate on two separate virtual servers. With 16GB of RAM and a 2.3GHz dual-core processor, the Kafka Broker virtual computer is powered by the CentOS operating system. A 2.4 GHz CPU, 2 GB of RAM, and the Ubuntu operating system power ZooKeeper. QoM-DB is installed on an independent virtual machine on OpenStack Cloud. Ubuntu is the operating system running on this virtual computer, which also features the 2.3 GHz processor and 2 GB of RAM.

Using the programming language Python to build QoM-DB as an HTTP server during setup within a Linux environment. DH operating on a virtual computer in the HP Matrix cloud. The video card features two gigabytes of RAM, a 2.3 GHz CPU, and the Ubuntu operating system. Furthermore, we used the Java Development Kit to build DH in the programming language Java and test it in a Linux environment. The Network Operator Center that handles M-Plane data is modeled by the consumer. The simulated NOC will act as the real NOC in a real network environment, employing KPIs to monitor NT. was used in our configuration to deploy an imitated NOC on a virtual computer in the HP Matrix cloud. This virtual computer features a 2.4 GHz processor, 4 GB of RAM, and the Ubuntu operating system. The simulated NOC was implemented as an HTTP server using the Python and JavaScript computer languages, and it was then subscribe using DH.

3.2. LTE network data

We collected raw M-Plane data for the experiment using a real LTE networks network in Northern Europe. Hourly measurements were recorded over the roughly four weeks of data collecting. This work is licensed under a Creative Commons Attribution 4.0 license. Next, we computed four distinct KPIs for assessment. To see if the KPIs adhered to conventional statistical distributions, we used the Cullen and the Frey test [26].

The investigation revealed that the majority of KPIs fit the Beta distribution [27]. As a result, we are able to determine the average deviation σ for every KPI. Below is a list of four KPIs with various statistical properties: LTE 5017a: Static KPI, with a value that seldom varies and a median of 100 ($\sigma = 0.02$). LTE 5178a is a very static KPI (median = 99.65; $\sigma = 2.1$), with a mean value of 100 and sporadic variations. KPI LTE 5518a frequently fluctuates in value; it is non-static (median = 1001.93; $\sigma = 321.32$). KPI LTE 5520a, which fluctuates in value often (median = 906.04; $\sigma = 315.6$), is non-static.

Comparing different compression techniques: Lossless archiving and compression techniques like tar, gzip, xz, bzip2, and zip enable superior raw data restoration from compressed material. By eliminating any empty areas or repeated bit patterns that might be present in the files, this approach enables information being stored in a dense manner [28]. Sadly, these techniques have serious shortcomings when used on streamed series of NE performance information, which are collections of values representing different performance metrics and characteristics. However, each data point on its own is quite little when compared to the sum of all M-Plane information points over the same timeframe.

Furthermore, every data point contains a tiny amount of redundant bit patterns. As a result, the gain per data point from conventional lossless compression approaches is minimal. When decompressing the data, these lossless compression techniques also need access to the entire compressed bit stream, which is not feasible in a real-world network setting. This is because losing any of the of the Danix points might prevent the remainder of the stream from being unpacked. Compare this to time series data that has been compressed using lossy methods. This will cut down on data tremendously. One compression technique is the PWCA, which uses a constant value such as a slice or median to represent a series of successive data points. These neighboring data points are regarded as a single unit.

The PWCA system includes algorithms that are utilized both offline and online [29]. When it comes to archive time series information at the database's end, standalone PWCA algorithms could be superior, but they are unable to compress M-Plane data at the source (such as in NEs in which high M-Plane data rates are necessary) [30], [31]. For QoM compression, we therefore suggest a modified online PWCA (mPWCA) method. The method presented in [31] serves as the foundation for this one. The mPWCA method gets around the PWCA algorithm's drawbacks by enabling quicker data collecting cycles. It also enables you to do away with superfluous data transfer, which lowers energy usage. Algorithm 1 illustrates our proposed mPWCA's reasoning. 1. KPI series compression via the mPWCA technique.

1. Create a set S = [s[1], s[2], · · ·, s[n]].
2. Establish the limit on information loss (Iloss > 0).
3. Assign PWCA(s) to = ()
4. Assign i to 1.
5. Assign m to 0.
6. Assign 0 to PieceConstant
7. Set CurrentPiece = (step 7)
8. m = S[I]; while (S.hasMoreValues()) do
9. CurrentPiece.clear() if (| PieceConstant - m | > Iloss) then
10. add to CurrentPiece add(m,i)
11. Add CurrentPiece[0] to PWCA(s) in step 13.
12. PieceConstant = CurrentPiece[0] on line 14.[0]
13. additional
14. add to CurrentPiece(m,i)
15. terminate if 18: i=I+1
16. Release the PWCA(s)
17. the conclusion

S = [s[1], s[2], · · ·, s[n]] and (Iloss > 0) are the online time series that the algorithm employs as inputs. The method then generates an accelerated time series online on line 19 during output. To create the time series PWCA(S) within Iloss errors, the method compressed an interactive time series S = [s[1], s[2], · ·, s[n]. Where Iloss for a particular QoM class might be an operator or the information loss limit. Line 10: If and only if the divergence from the current part constant is less than the information loss limit (Iloss) set for compression, the algorithm determines if every data input point is an element of the current part.

All of the information points falling under a single part are displayed in lines 11 and 12 by the compressed series' part constant. A new P-constant is created between lines 13 and 14 when a new part is created, and that constant will be added to the compressed list. Line 16 adds the data point to the current part if its departure from the constant current of the part is smaller than the data loss limit.

3.3. Compression ratio

Two phases are involved in solving QoM via data compression. LTE KPI data is first aggregated from raw LTE data using KPI calculations, and subsequently lossy compression of the LTE KPI data is carried out using an implementation of the QoM class. First, we integrate LTE KPIs at the mobile device edge with LTE counter data. Such aggregation leads to a large reduction in the volume of data. Assuming that an operator is interested in N KPIs and that k counters are needed for each KPI in order to compute the KPI. Assuming these KPIs are not computed at the network border (i.e., DF in this document), (N × k) values for data will be transferred. It should be mentioned that various LTE KPIs employ varying numbers of counters in their calculations, therefore each KPI will have a different value for k.

The k counter's lowest and largest readings throughout our observation were 1 and 27, respectively. The initial LTE KPI network information included this value. Actually, thousands of parameters can be generated by each NE, a few of which are being updated every second. For instance, each NE generates around 2800 parameters in the live LTE data utilized in this work. Take note that each network comprises a sizable number of work elements, or NEs. As an illustration, a sizable 5G network may have up to 100,000 NEs. An imaginary data transport scale of 105 × 2800 × 1/s × x bytes may be obtained if we suppose that there are x NEs. This corresponds to 280 × x MB/s. The amount of data sent will drop to 28 of the MB/s per KPI once the KPI resolution is finished, assuming that the average value of the 10 KPI variables is lowered.

QoM compression will lower this number in the second part of the QoM method, as will be detailed below. In the second phase, we experimented to identify the QoM class that the network operator had specified using data and techniques. The aim of the study was to assess the compression gain attained by the QoM methods and demonstrate the effectiveness in applying lossy compression (as detailed in Subsection V-C) to the computed KPI data. (1) Definition of the network operator class: In our analysis, there is a correlation between the quantity of KPI data points and the number of transactions. It is necessary to move these data items from DF to DS. For each of the 4 KPIs in the experiment, we compressed DF using a different set of information loss restrictions.

Furthermore, K was raised from 0.0 to 1.5 and the KPI information loss constraints were specified as ($K \times \sigma$). Each NE – in our example, the eNB – generated an identical set of KPI data. Keep in mind that if KPI data originates from many networks, its distribution is network dependent. However, KPI data is frequently shared among elements with comparable contexts if it originates from the same network. Four KPIs' worth of data, all originating from NEs in the same network, were used in the experiment. After converting all the time series data to QoM compression, the outcomes were compiled at the network level. It doesn't notice any change since our test data is sourced from a single network, and the outcomes are obtained by a deterministic approach that yields consistent findings for that dataset each time.

The outcomes of the classes that the network operator established are displayed in Figure 3.2. The amount of anticipated data loss while utilizing the compression technique in the suggested QoM solution is made clearer by this information. The compression of the KPI data utilizing various information loss restrictions ($K \times \sigma$) is shown in Figure 3.2(a). This picture illustrates how, when the information's loss limit (K) rises, the number of transactions – that is, the quantity of KPI data that must be transferred – decreases dramatically. The efficacy of employing a defined class method based on the networks operator is demonstrated by the decrease in all KPIs. As can be seen in Figure 3.2., K and the quantity of transactions have a linear correlation.

The total amount of transactions is greatly decreased as K increases, which results in a large compression of points of data. For instance, by selecting $K = 0.2$, the suggested mPWCA method compresses a significant quantity of data for all KPIs. The red data capacity of the LTE-5518a has nearly decreased in half. Additionally, compressing the data considerably with a greater K value leads in a loss of extra information.

However, the compression decrease rate is almost constant when K = 0.6. Figure 3.2.(b) displays the fluctuation in the compressed time series data's mean squared error. This inaccuracy is indicated by this proportion of the associated time series' median value.

Like information loss limits and K values rise, all KPIs exhibit a little rising trend in MSE, as seen in the figure. The total number of MSEs for each KPI rises with each increment of K. At K = 0.2, the compression rate ratio is modest, while at K = 1.2, it is high. In fact, when MSE values are high, the suggested approach is ineffectual, which implies that although it effectively compresses a lot of data, information is lost. For example, using K = 1.2 will result in over 100% more data compression. High MSE numbers and data loss for some KPIs will result from this.

In this scenario, data that is useful for some monitoring activities could still be present in certain other KPIs. The findings in the figures demonstrate that the optimal value of K should be 0.6 since the mPWCA method ensures effective compression. In actuality, this is the ideal number to guarantee the QoM solution's optimal performance.

The outcomes also demonstrate how well the mPWMC algorithm solves QoM. These results may be utilized by network operators in order to determine data loss limits (or select the amount of K) for different QoM classes, as K = 0.6 would be the optimal limit number in this scenario. (2) Determining the QoM class using data: Because the spatial distribution of KPI data varies in actual cellular networks, we utilize the total sequence deviations σA as a model to find the information loss boundaries for QoM classes. Consequently, we establish a set of absolute sequential deviations (σA) for the time series data set X in which X = (x(1), x(2),..., x(k)), where x(k) ∈ R denotes the quantity of the real-world process at any given time k. We then observe the distribution of these values in each transmitted time series across the training phase.

The statistics indicator σA may be utilized to ascertain the data loss limit for QoM classes. α displays danix. As a result, it enables the operator to decide which variations between successive KPI values are too small for compression and which should be shared with the customer. Furthermore, it takes minimal computing to observe each σA's distribution of values, which makes it appropriate for use on MEC systems.

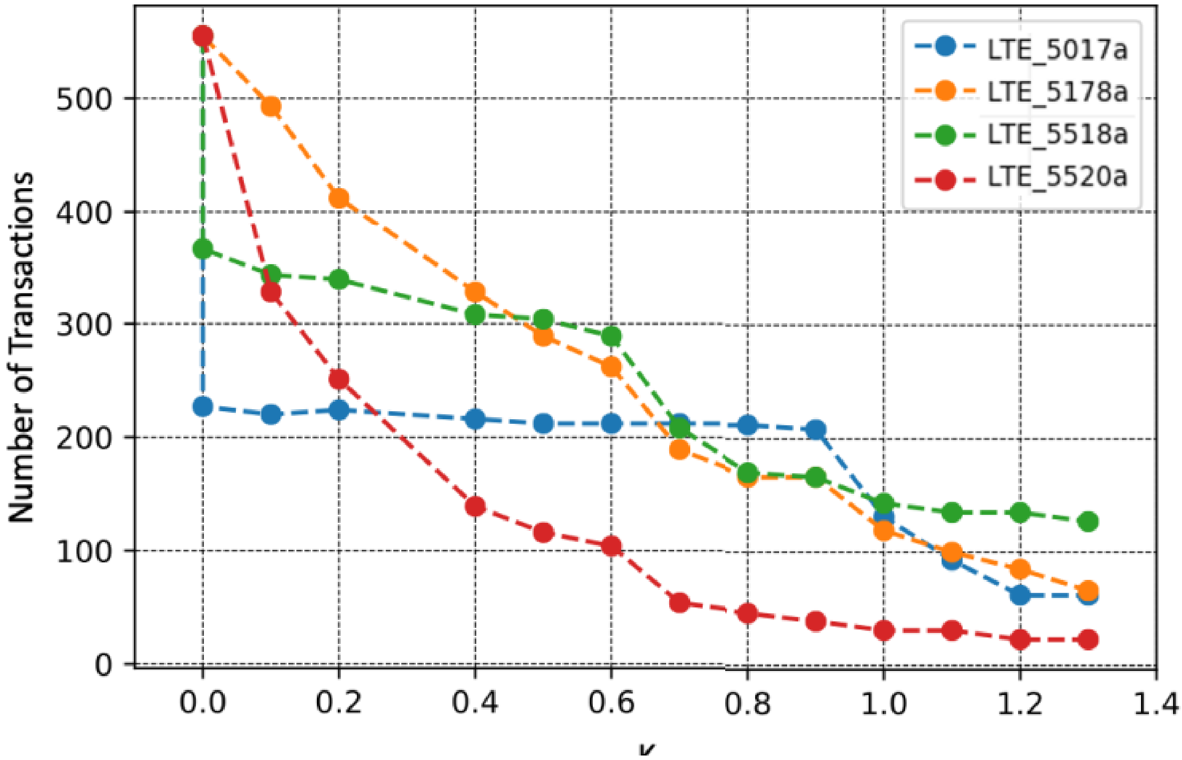
It created three QoM categories in our implementation as a result.

Specifically, the information loss threshold was established at 0. Additionally, we determined the data loss limit (represented by Iloss in Algorithm 1) using σA as a measure.

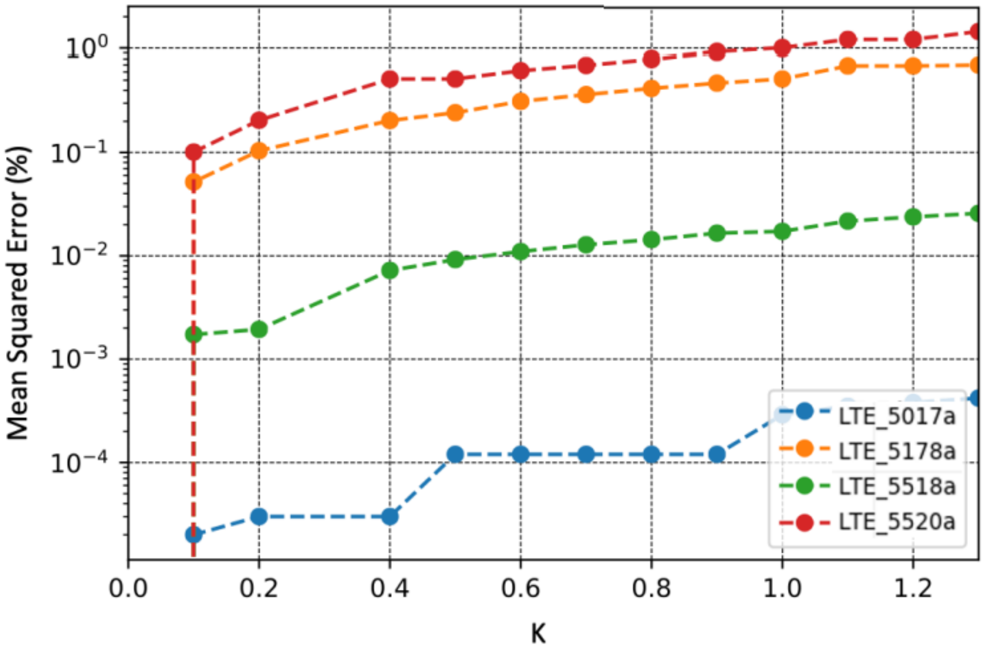
Class optimization: 25% σA of the training information was chosen as the information loss limit. Stroke class: 50% of σA of the training data was designated as the information loss limit.

Future improvements might be made to this data-driven approach for determining the QoM class. By identifying additional redundancy and connections from the time series, lightweight ML techniques may be used to increase the method's accuracy. For instance, unsupervised grouping of M-Plane data may be used to identify recurrent system conditions in which variances between subsequent values may change. One such technique is the algorithm for clustering K-Means, which is among the most widely used unsupervised learning algorithms [32].

It's true that the K-Means clustering method may form clusters by assembling previously undetected instances of a data set according to common traits. Furthermore, a fast-sensing technique that can compress big data sets in real time is the K-means clustering method [33]. The following stage is to begin compressing many KPIs and train DF for a duration of two weeks. We counted the total amount of KPI transactions at the beginning of compression during implementation in order to calculate the compression gain. The total compression results, acquired by compression the KPI information for the three qualities of QoM classes, are displayed in Table 3.1. These results include the compression percentage and the error rate. The KPI value is shown in MSE results as a percentage of the average KPI value.



Compression achieved by different KPIs.



(b) Mean square error of the compressed KPI data series.

Fig. 3.2. Compression achieved and Mean Square Error concerning different information loss limits (k × σ) used for the compression (a), (b)

Table 3.1

Compression and error for different KPIS achieved by data-driven QOM class compression

	Class Exact		Class Optimized		Class Sharp	
KPI ID	C(%)	E(%)	C(%)	E(%)	C(%)	E(%)
LTE_5017a	63.78	0.00	63.78	0.00	63.78	0.00
LTE_5178a	37.66	0.00	37.66	0.00	53.15	0.28
LTE_5518a	6.3	0.00	38.92	3.24	71.35	11.49
LTE_5520a	4.5	0.00	36.22	5.82	52.97	12.27

The compression ratios are listed in Table 3.1 Let's examine the actual case that we previously reviewed in Subsection V-D's second paragraph. After the KPI was calculated, the data volume there dropped from 280 ×x MB/s to 28 ×x MB/s = V. We will now examine every component of the network. Assume that 10% of the NEs require precise data for the network to function. The precise QoM class is going to be used in this instance. For forty percent of NEs in a network, the QoM Optimized category will do. For all other NOs, the Sharp type is appropriate. Assume next that the KPI categories under analysis are evenly distributed NE KPI types.

By taking the mean compression benefit of each class, we can thus estimate the accomplished compressing in the KPI NE for which each class was applied. Therefore, 63.78 + 37.66 + 6.3 + 4.5)/4 = 28 is the compression ratio of the Exact class, as seen in the case study from Table 3.1. As a result, the Optimized and Sharp classes have compression ratios of around 44 and 60.The data volume reduction of KPI V may thus be directly estimated as follows: (1 - 28/100) × (10/100) × V + (1 - 44/100) × (40/100) × V + (1 - 60/100) × (50/100) × V = 0.5 × V. As a result, the information transfer rate drops from 280 × x MB/s to 14 × x MB/s. Comparing this to the initial data rate, we get a compression increase of almost 95%.

QoM Resource Utilization Our QoM solution is implemented on MEC platforms, which are known to have constrained CPU and memory resources [34]. As a result, using programs that need a lot of processing power might interfere with the MEC environment. In order to do this, we assess the QoM solution's memory and CPU use. In experiment, which we reported in Subsection V-A, was measured the amount of computing resources consumed by using two subscriptions per NE.

The first subscription transmits the KPI data that DF computed from the raw M-Plane data, while the second subscription transmits the streaming resource use of DF. The DFs were then set up to track the amount of computing resources used during each iteration with the DF and to compute and report an increasing number of KPIs at each iteration. Furthermore, the quantity of DF resources was quantified using the Linux Collectl tool [36]. It studied QoM compute resource use by running our testbed twice. both before and after a QoM solution is put into place, as explained below: Without a QoM configuration In this experiment, we kept an eye on how much DF resources were being used up until the QoM solution was put into practice. DFs were meant to, among other things, calculate and publish KPI data in DS, retrieve the KPI equation from QoM-DB once at the start of the subscription, and obtain the appropriate counters from the M-Plane data. When QoM is configured:

DF resource use was monitored in this experiment while the QoM idea was put into practice. We spent five weeks using the M-Plane data. After that, we split the experiment into two stages: the learning stage and the compression stage. A learning phase is necessary if the QoM class definition is not defined by the network operator in the QoM-DB. DFs learn the definition of the QoM class and do not execute compression during the training phase. We extend our experiment to a training phase until DF establishes the QoM class definition by analyzing the M-Plane data for at least two weeks. Following the training phase, the compression step involves compressing KPI data. In the training and compression stages of our experiment, we measured how much computational power DF used, as detailed below. In order to compute the KPI equation from the QoM-DB and to collect the counters required to do so from the M-Plane data, both DF steps are purposefully built.

Furthermore, understanding how to construct QoM classes and publish KPI data without compression was part of the DF training process. Furthermore, the compression step is made to compress KPIs in accordance with the QoM class that QoMDB defines. The DF published the brief KPI data to the DS after resorting to the QoM class definitions it had acquired in the event that the QoM-DB definitions were unavailable. Outcomes of Resource

Utilization: Table 3.2 shows the CPU and memory use performance measurements taken throughout the experiment, both with and without the solution's QoM implementation.

Table 3.2

CPU usage and available memory for data storage with 200 KPI sub-payment

	With QoM		Without QoM
	Train	Compress	———-
Mean CPU utilization	25.5%	28%	22%
Median CPU utilization	25%	27%	21%
Available memory	$\simeq$ 89 MB	$\simeq$ 80 MB	$\simeq$ 240 MB

Without doing QoM adjustment, the results revealed that when KPIs were subscribed, CPU consumption rose approximately linearly. Average CPU utilization was the KPI for 200 subscribers. This work is licensed under a Creative Commons Attribution 4.0 license. Look for further details. Before it is published in its final form, content may change. Information about around 22% and 21%, respectively, may be found in IEEE Transactions on Network and Service Management 9. Reference: 10.1109/TNSM.2021.3112467. The CPU use was pretty high during each cycle when the KPI subscription started. This was not perceived as CPU utilization, but rather as startup overhead. Memory use is high as seen by the results of executing KPI computations and subscribing to 200 KPIs.

This indicates that about 240 MB of the 800 MB of CPU memory are available for utilization. The CPU and memory consumption on DF were greater in the QoM-set experiment than in the non-QoM-set studies, according to the findings obtained from the training and compression phases. Table 3.2 illustrates that during QoM implementation, the available RAM during the training and compression stages was 89 MB and 80 MB, respectively.

However, in the event that QoM was not used, there was 240 MB of RAM that was accessible. Similarly, throughout the training and compression stages, the CPU utilization was 25.5% and 28%, respectively. When QoM was not implemented, CPU use rose and memory became less accessible. Given that the operation in both tests makes substantial use of the available resources, these findings are in fact expected. For instance, RAM was around 560 MB before installing QoM, and it increased to 711 MB and 720 MB after training, respectively. Furthermore, the outcomes are acceptable since the resources needed to execute the QoM system are available.

3.4. Comparison with modern

To sum up, workflow strategies make the most use of the resources at hand by employing lossy and conventional compression methods. Various data sets with varying data sizes, kinds, and formats are used in these investigations. While some studies evaluate conventional compression techniques, others improve resource utilization with ML algorithms. While the ML methods employed in the study vary, a CPU is needed for certain tasks, and a GPU is needed for others in order to evaluate performance. In fact, it doesn't seem reasonable to compare the findings of this paper with those of contemporary study. Considering that our usage of the datasets and approaches will be different from those stated in the literature. For instance, [17] employed an artificial intelligence-based lossless compression technique.

It makes use of a dataset that has short strings—an average of 160 characters—in it. With an 84.31% compression ratio, this study has so greatly decreased the amount of the data. A research [18] combines a lossless compression technique with a network of recurrent neural networks for prediction to decrease datasets by around 20% when compared to Gzip using genomics and text datasets. In contrast to Gorilla, Middle-Out, and Snappy compression approaches, a reinforcement learning-based technique was utilized in [19] to compress data from time series and increase the ratio of compression up to 120% (50% on average). We will investigate the method's bandwidth consumption for Gorilla, MO, and Snappy on a CPU+GPU platform.

The findings demonstrate the stability of Gorilla and MO, with average performance of around 100MB/s and 1.3GB/s, respectfully. The speed of Snappy fluctuates a lot and usually exceeds 60MB/s. Subsequently, the work's compression efficiency is assessed using the graphic processor; it approaches 900 MB/s. In order to reduce the amount of M-Plane data, this study suggests using the idea of QoM, which involves deleting data that is redundant and has the least amount of information at the network's edge. At the network's edge, the QoM solution collects data into KPIs inside classes and uses lossy compression to compress it. The QoM solution requires enough CPU and memory resources to function and has a good compression ratio for three classes with varied loss restrictions, according to the implementation findings applied to the KPIs of real LTE networks.

3.5. Research using Python

Based on the research from Figure 3.3. this study was examined in more detail and the results were summarized. Specifically, comprehensive analysis was performed and Python was used to explore and visualize key aspects of the study using the PyCharm program and the matplotlib.pyplot library.

Benefits of Compression: with the help of the code Figure 3.3. bar chart Figure 3.4. was constructed, which displays the benefits of compression for each KPI and QoM class.

```python
import matplotlib.pyplot as plt

# Data for the compression benefit graph
kpi_labels = ['LTE 5017a', 'LTE 5178a', 'LTE 5518a', 'LTE 5520a']
class_labels = ['Class Exact', 'Class Optimized', 'Class Sharp']
compression_percentages = [
    [63.78, 37.66, 6.3, 4.5],
    [63.78, 37.66, 38.92, 36.22],
    [63.78, 53.15, 71.35, 52.97]
]

# Construction of a bar chart
fig, ax = plt.subplots()
bar_width = 0.2
opacity = 0.7
index = range(len(kpi_labels))

for i, class_label in enumerate(class_labels):
    plt.bar([pos + i * bar_width for pos in index], compression_percentages[i], bar_width,
            alpha=opacity, label=class_label)

plt.xlabel('KPI')
plt.ylabel('Compression Percentage')
plt.title('Compression Benefits for Different KPIs and QoM Classes')
plt.xticks([pos + bar_width for pos in index], kpi_labels)
plt.legend()
plt.tight_layout()
plt.show()
```

Fig. 3.3. The code for diagrama Compression benefits for different KPIs and QoM classes

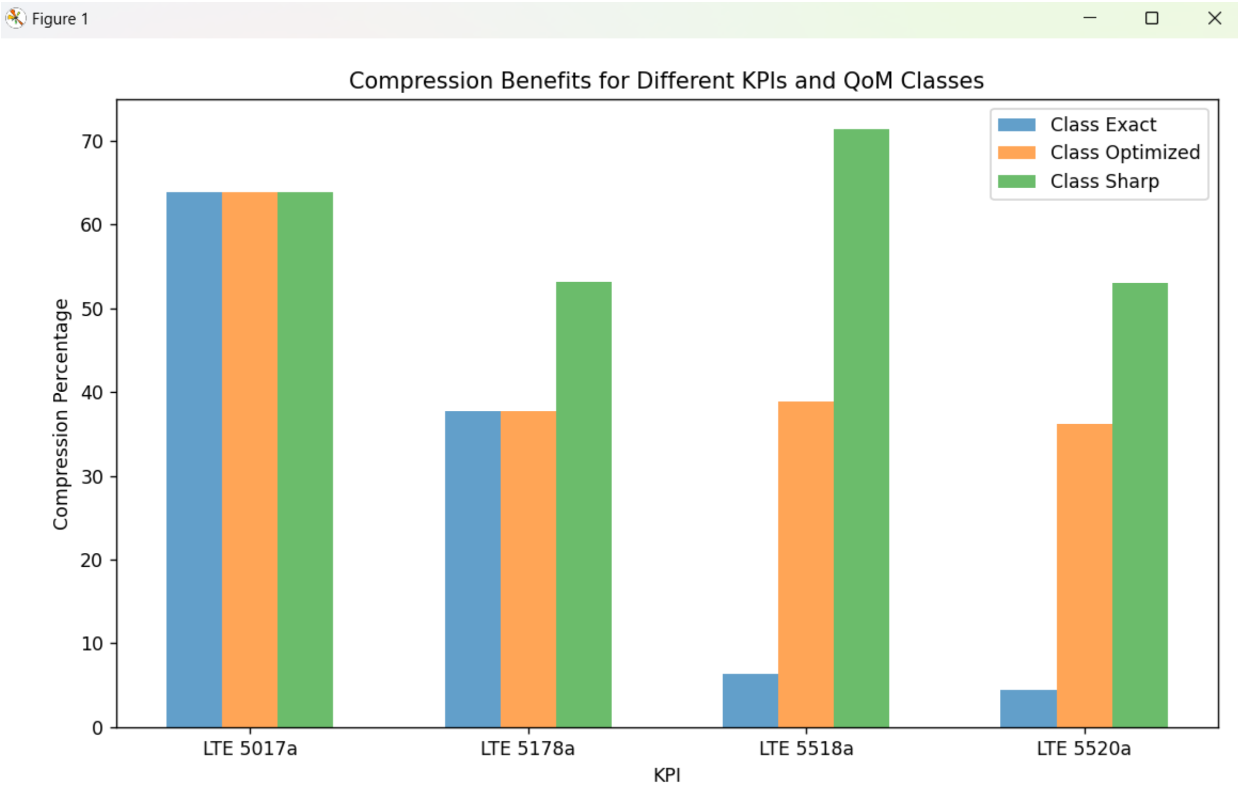


Fig. 3.4. Compression benefits for different KPIs and QoM classes

The graph allows you to compare the effectiveness of different compression levels and determine the optimal QoM class for each KPI. The results were presented as percentage compression values for better understanding.

The graph Figure 3.6. was created. using the code Figure 3.5.

```
# Data for the graph of resource consumption
phases = ['Train', 'Compress']
cpu_utilization_without_qom = [27, 28]  # In the absence of QoM
cpu_utilization_with_qom = [25.5, 28]   # When installing QoM
memory_available_without_qom = [240, 80]  # In the absence of QoM
memory_available_with_qom = [89, 80]  # When installing QoM

# Construction of the schedule
fig, ax1 = plt.subplots()

ax1.set_xlabel('Phases')
ax1.set_ylabel('CPU Utilization (%)', color='tab:red')
ax1.plot(phases, cpu_utilization_without_qom, color='tab:red', marker='o', label='Without QoM')
ax1.plot(phases, cpu_utilization_with_qom, color='tab:orange', marker='o', label='With QoM')
ax1.tick_params(axis='y', labelcolor='tab:red')

ax2 = ax1.twinx()
ax2.set_ylabel('Memory Available (MB)', color='tab:blue')
ax2.plot(phases, memory_available_without_qom, color='tab:blue', marker='s', label='Without QoM')
ax2.plot(phases, memory_available_with_qom, color='tab:cyan', marker='s', label='With QoM')
ax2.tick_params(axis='y', labelcolor='tab:blue')

fig.tight_layout()
plt.title('Resource Utilization with and without QoM')
plt.show()
```

Fig. 3.5. The code to the graph “Resource Utillization with and without QoM”

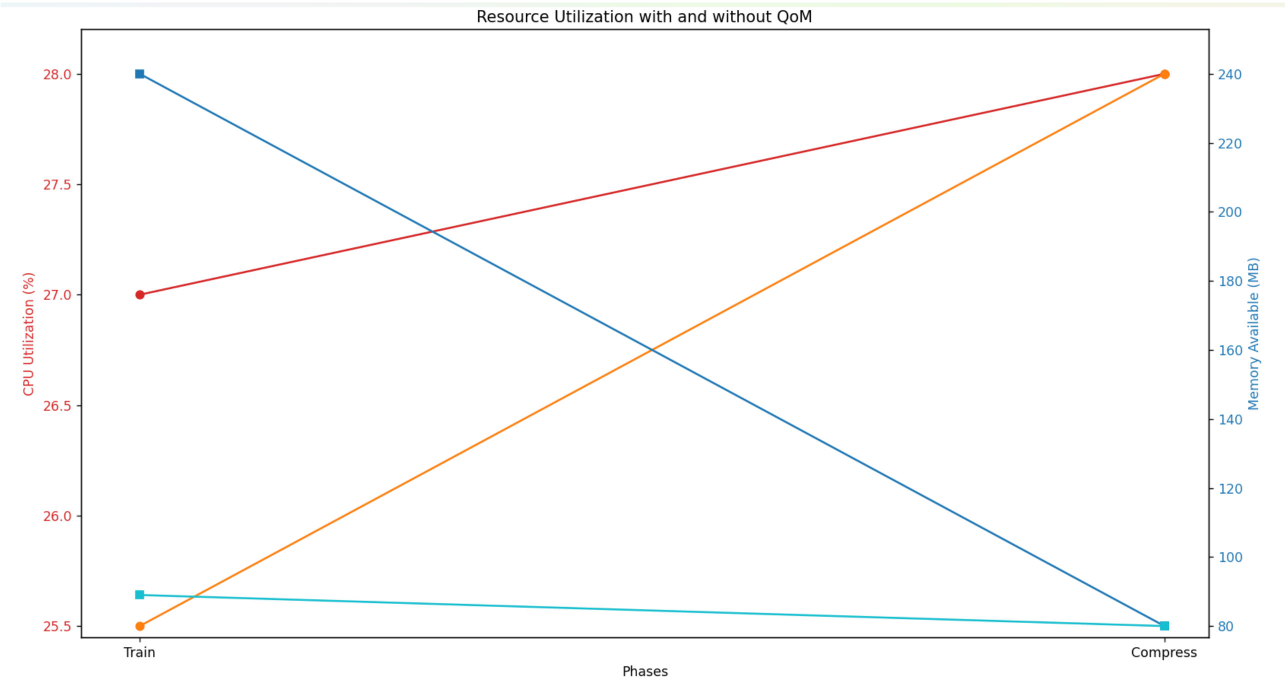


Fig. 3.6. Resource utillization with and without QoM

Resource consumption: the graph shows CPU usage and available memory with and without QoM installed. The graph indicates the impact of introducing QoM on resource utilization and operational efficiency. The results are displayed as a line graph for ease of comparison.

The graph Figure 3.8. was created using the code Figure 3.7.

```
# Data for comparison with existing technologies (approx.)
existing_technologies = ['AI Lossless Compression', 'RNN Predictor + Lossless Compression', 'RL-Based Compression']
compression_reduction = [84.31, 20, 50]  # Приблизно відсоток зменшення обсягу

# Building a comparison chart
plt.figure(figsize=(10, 6))
plt.barh(existing_technologies, compression_reduction, color='skyblue')
plt.xlabel('Compression Reduction (%)')
plt.title('Comparison with Existing Technologies')
plt.show()
```

Fig. 3.7. “Comprasion with existing tecnhologies”

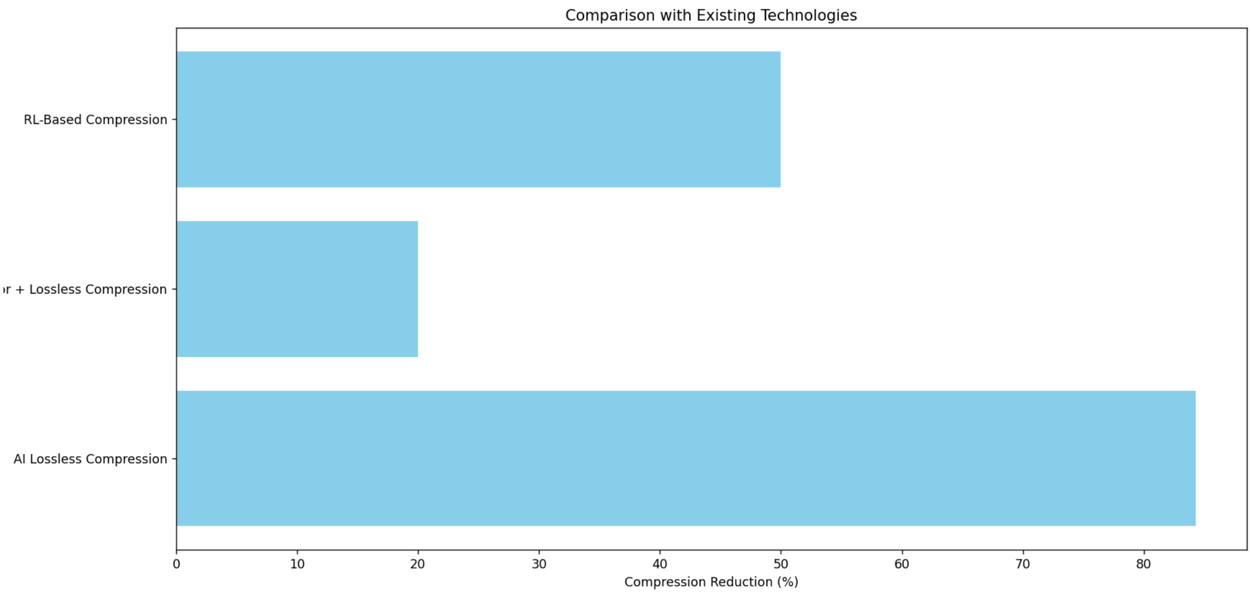


Fig. 3.8. Comprasion with existing technologies

Comparison with Existing Technologies: a comparison chart is made showing the benefits of QoM compression compared to existing technologies. The graph makes it possible to understand the competitiveness of QoM compared to modern compression or ML technologies. A horizontal bar chart is used to better highlight the differences.

These graphs and charts are a key element of the study and help to visualize and understand the results obtained during the analysis of the quality of control and management in mobile networks, particularly in the context of 4G and 5G technologies. Cellular communication networks are evolving rapidly and appear with an increasing number of network infrastructure and elements. Current network monitoring solutions will face fundamental challenges in the future, if they continue using the conventional approached of monitoring the M-Plane data. While the increasing number of NEs generate more and more data; a significant portion of this data includes redundant or small information content which translates to the least significant and has no value for monitoring.

In this paper, was presented the concept of Quality of Monitoring (QoM) as a solution for monitoring the M-Plane data which aggregates the data into KPIs and uses a set of classes to compress data at the mobile edge before monitoring. While the QoM solution uses a set of classes which each has a different information loss limit that can be defined by the network operator or can learn it using data-driven or ML methods at the network edge. The

QoM then applies a lossy-compression algorithm called mPWCA algorithm to further compress the data. Was evaluated the performance of the QoM solution using raw M-Plane data from a live LTE network and computed four KPIs, such that each KPI has a different statistical characteristic.

The results show the significant performance of the QoM solution by considerable compression of the M-Plane data at the network edge and efficiently utilizing the network edge resources such as the CPU and the memory.

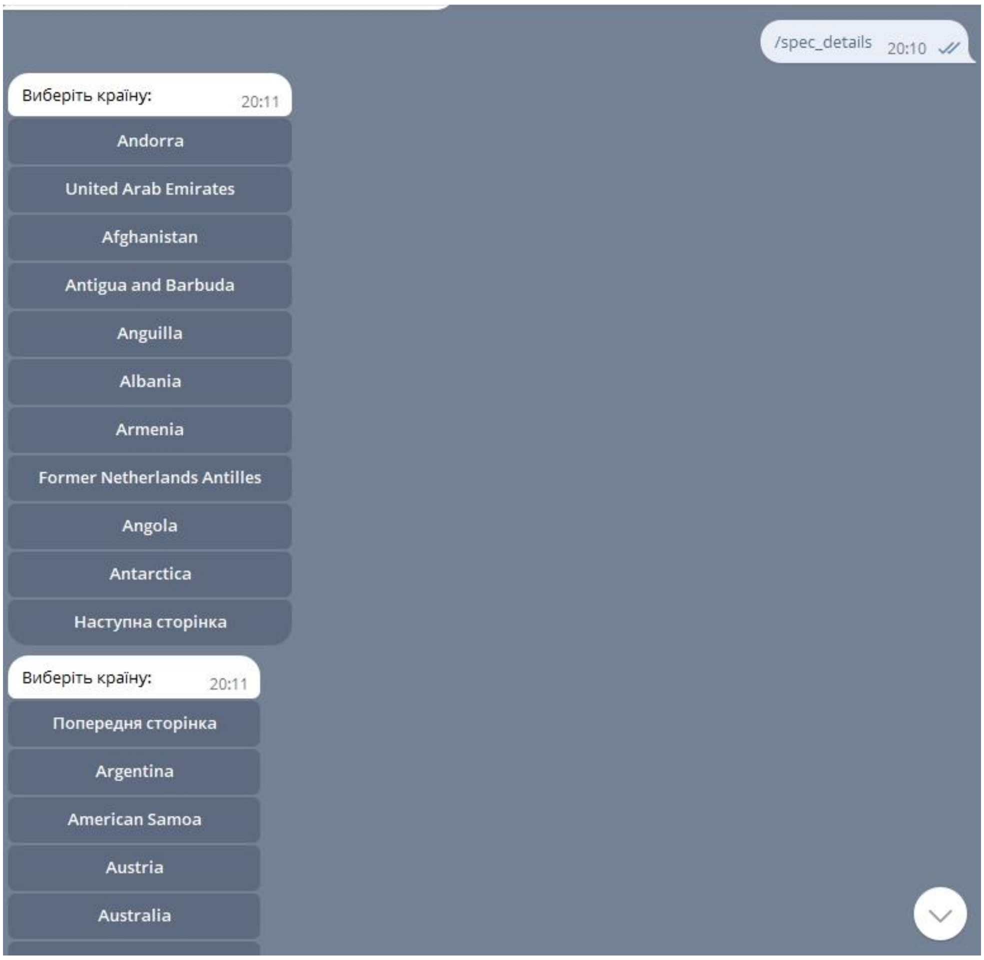
3.6. Telegram bot for users to improve QoS conditions

The master's thesis is aimed at studying aspects of quality and management of mobile networks, especially in the context of transitional technologies 4G and 5G. For this, a bot was created to analyze and present information about mobile operators in different countries, including their support for 4G and 5G technologies.

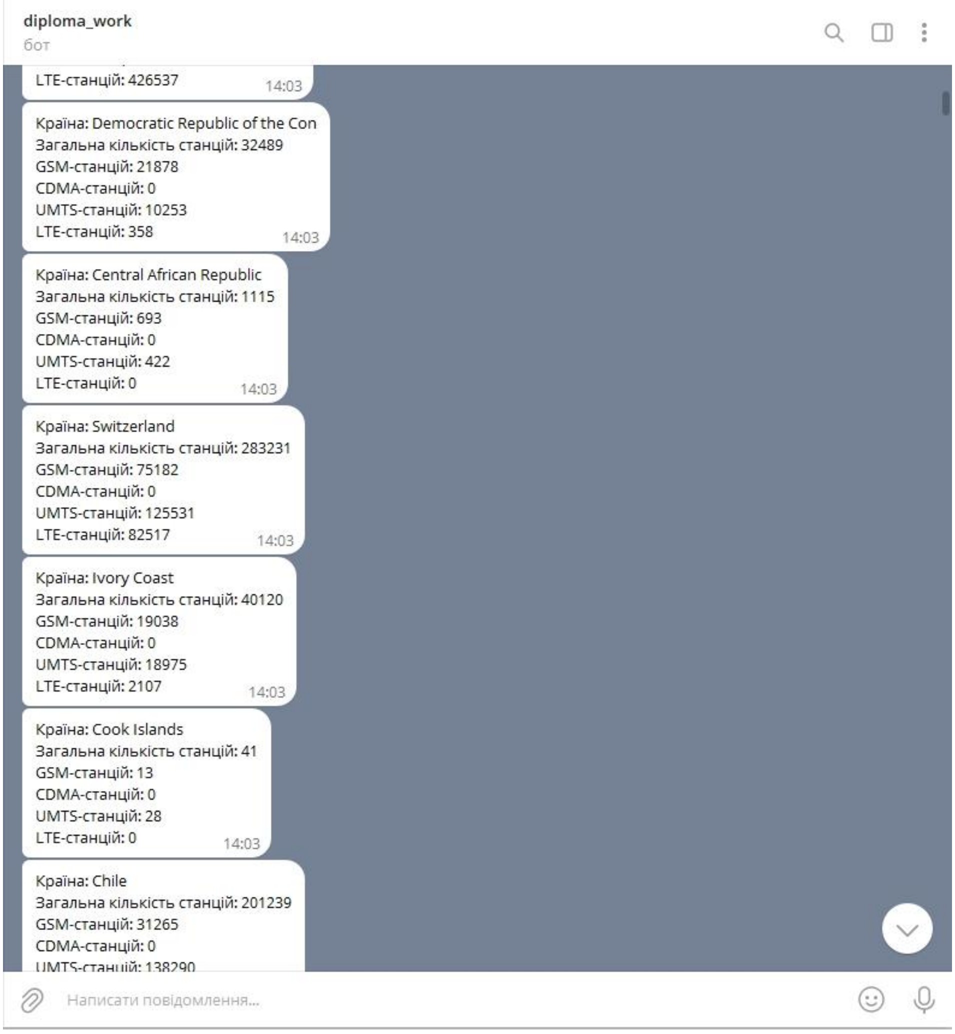
A bot is a key tool for studying and understanding various aspects of mobile networks. First of all, it can be used to collect and aggregate technical data from various sources related to modern mobile technologies. This includes information about the types and number of network stations, their characteristics and supported technologies.

The bot serves as an interface for convenient visualization of this data, allowing users to easily familiarize themselves with the technical aspects of the network. This is especially important because 4G and 5G networks differ in their technical characteristics, and understanding these differences is key to effective mobile network management.

The following functions have been developed to enhance interaction with the bot. From real-time monitoring to obtaining information about different countries and operators, these commands offer a diverse range of features. Additionally, you can access global mobile network statistics or provide feedback on the bot's performance. A function has also been implemented to provide guidance on command usage and capabilities.


/spec_details 20:10
Виберіть країну: 20:11
Andorra
United Arab Emirates
Afghanistan
Antigua and Barbuda
Anguilla
Albania
Armenia
Former Netherlands Antilles
Angola
Antarctica
Наступна сторінка
Виберіть країну: 20:11
Попередня сторінка
Argentina
American Samoa
Austria
Australia

(a)



(b)

Fig. 3.9. The command /spec_details (a), (b)

/spec_details: This command shows a list of different countries around the world. Information about the total number of stations, GSM stations, CDMA stations, UMTS stations, LTE stations is displayed for each country.

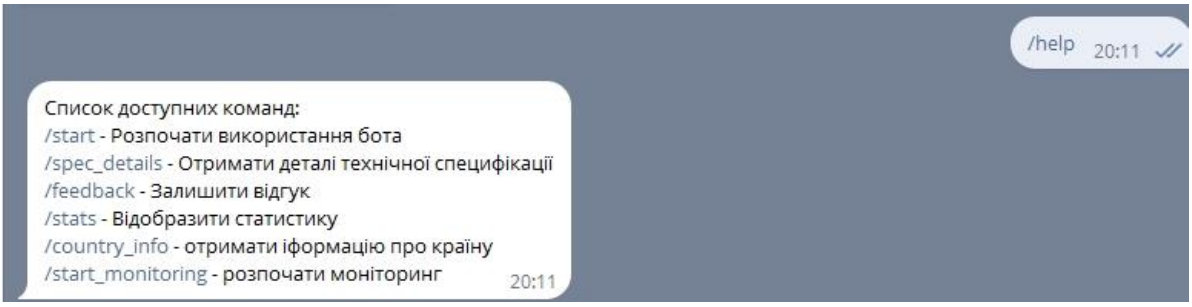


Fig. 3.10. The command /help

/help: This command calls the help function and is intended to provide the user with help or instructions on how to use the bot. It contains a description of the available commands and their capabilities.

Fig. 3.11. The command /feedback

/feedback: This command is used to send feedback or feedback about the bot's performance. This can be useful for improving functionality or correcting possible shortcomings.

Fig. 3.12. The command /stats

/stats: This command calls the stats function and is intended to provide the user with statistical data about various parameters of mobile networks. This may include information about traffic, network load, and other key metrics.

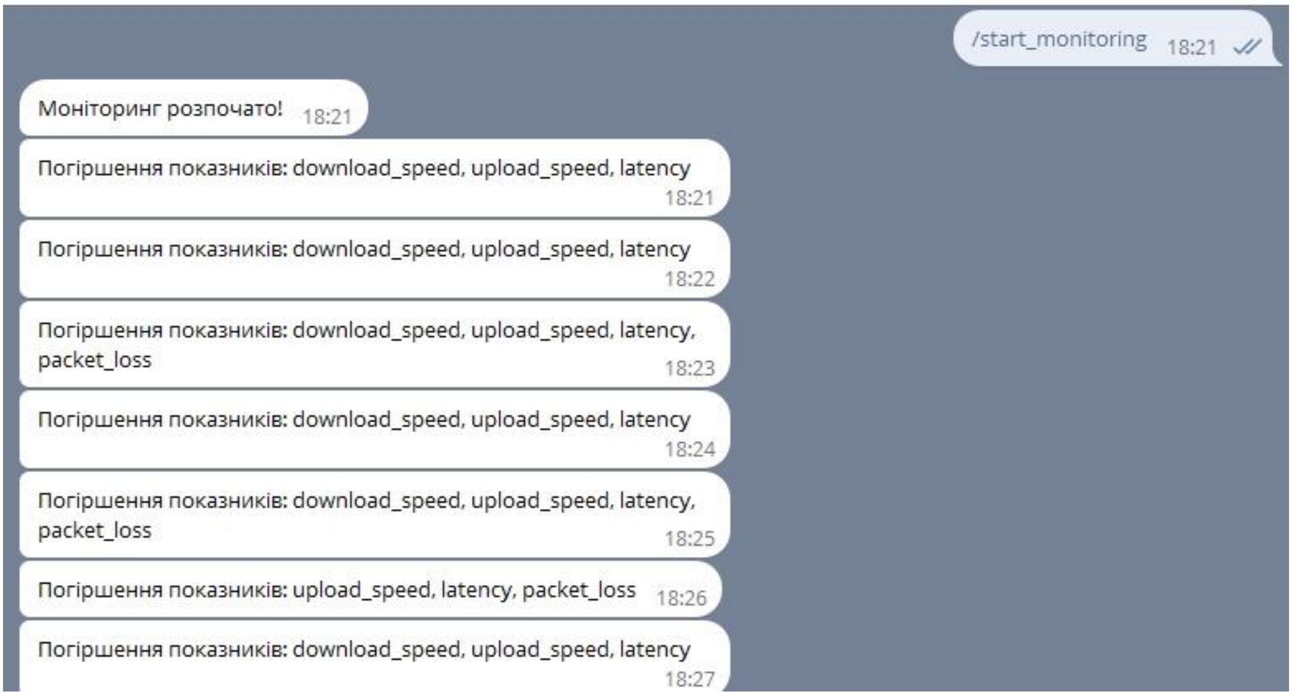


Fig. 3.13. The command /start_monitoring

/start_monitoring: This command activates the start_monitoring function, which can start monitoring various mobile network parameters in real time. This can be useful for tracking changes and analyzing dynamics in service quality and other indicators.

Fig. 3.14. The command /contry_info

/country_info: This command calls the country_info function and is intended to provide the user with information about a specific country or operator from a list stored in the program. The information may include technical data, statistics and other relevant information.

In addition, in the future the bot can function as an educational tool, disseminating technical information about 4G and 5G technologies. He can answer users' questions, explaining the basic concepts and technical aspects related to the application of new technologies in mobile networks.

In addition, in the future, the bot can provide the ability to monitor and analyze various network parameters in real time. Users can observe changes in the QoS and other key indicators during the introduction of 4G and 5G technologies.

Summarizing, the bot is not only a tool for analyzing technical data, but also a means of simplifying interaction with this information for users, which helps them better understand and use the new opportunities brought by 4G and 5G technologies in the field of mobile networks.

CONCLUSION TO CHAPTER 3

This chapter presented extensive research aimed at optimizing workflows in mobile networks, particularly in the context of the transition from 4G to 5G technologies. The main emphasis was placed on data compression techniques, in particular on traditional methods and the use of ML algorithms.

The study points to the importance of using compression techniques to optimize the use of resources in mobile networks. In particular, the study points to the importance of considering the diversity of datasets with different volumes, types and formats to effectively compare results.

An important element was the use of the Python programming language for more detailed analysis and visualization of the results. Using PyCharm and the matplotlib.pyplot library, graphs were created to help understand compression performance for different KPI and QoM classes.

The analysis results show that the use of compression techniques, particularly QoM, can effectively reduce the amount of data at the network edge by using lossy compression techniques and dividing the data into classes for further optimization.

In addition, the work includes the development of a Telegram bot, which aims to analyze and present information about mobile operators in different countries, including information about support for 4G and 5G technologies. The bot acts as an interface for convenient visualization of technical information and can serve as an educational tool to spread technical knowledge about these technologies.

It is necessary to emphasize the importance of developing and implementing effective methods of data compression to optimize work processes in modern mobile networks, as well as to determine the prospects of using the Telegram bot as a tool for analyzing and monitoring mobile networks.

CHAPTER 4
OCCUPATIONAL SAFETY

It is critical to protect workers' health and safety at work in the information technology sector, especially in mobile networks. The aircraft company's IT department programmer plays a crucial role in occupational safety by taking into account the demands of 4G and 5G technologies. They provide safe and healthy working conditions throughout the whole software development process for network software.

An important part of evaluating safe working conditions is examining potentially dangerous and damaging elements that might appear when network equipment is operating. Careful consideration must be given to the physical and mental strain, the production environment, and the emotional and psychological stresses that may have an adverse effect on workers' health.

The aviation firm employs an IT programmer whose job entails actively contributing to the creation of software for network equipment control and diagnostics. They must, therefore, take precautions to reduce the dangers connected to their operations.

Programmers need to be aware of the risks associated with using the software they have produced, especially in the early stages of development. In addition to the caliber of the software they produce, the efficacy of their work is assessed by their capacity to guarantee worker safety and health over the whole system life cycle.

An essential first step is to put procedures in place for quality assurance and software monitoring, which may involve spectral graph analysis of network equipment signals. This method avoids flaws from having detrimental effects on worker safety and enables quick defect diagnosis.

Because the programmer works out of the airline company's headquarters office, there are extra requirements for maintaining occupational safety, especially with regard to infrastructure and access to IT systems. All of these factors highlight the necessity of paying close attention to workplace security and safety concerns for IT department programmers at every point of their careers.

4.1. Analysis of Hazardous and Harmful Factors Affecting the Programmer

Organization of the Programmer's Workspace

The workstation of a programmer plays a vital role in maintaining occupational health and safety. The space is 40 square meters in total, with a height of 3.5 meters at the ceiling and dimensions of 8 meters by 5 meters. There are six workstations with personal computers in this area. Each workstation has a 1.44 square meter desk, a chair, and a personal computer with a keyboard, mouse, monitor, and system unit. As per reference [1], every workstation need to have a minimum size of 6.0 square meters and a minimum volume of 20.0 cubic meters. Consequently, the space's proportions allow for the installation of six PC operators' workstations.

Risky and Dangerous Elements Impacting the Programmer

Hazardous factors are those that cause an employee's health to immediately deteriorate. A work environment's harmful elements are those that cause employees' health problems or disruptions in their productivity, either directly or indirectly.

According to [2], the programmer is subjected to the following dangerous elements: static electricity, inadequate illumination in the workstation, and microclimate.

The microclimate in the workspace of the programmer

Because programmers work in categories Ia and Ib, which are light work, they must comply with the following standards [3].

Table 4.1

Optimal values for temperature, relative humidity, and air velocity in the working area of production premises

Season	**Work Category**	**Air Temperature**	**Relative Humidity**	**Air Velocity. m/s**
Cold	Light Ia	22 - 24	60 - 40	0,1
	Light Ib	21 - 23	60 – 40	0,1
Warm	Light Ia	23 - 25	60 - 40	0,1
	Light Ib	22 - 24	60 - 40	0,2

The IT department's measured humidity and temperature match the values listed in the chart during the warm period. The room's six PCs produce heat, and the heating system's heated surfaces are employed to preserve the ideal microclimate conditions throughout the winter season. The surface area of the human body exposed to radiation determines the limits of the regulated parameter, infrared radiation density (Ig.d) (Sopr). For Sopr > 50%, g.d = 35 W/m2, Ig.d = 70 W/m2, and Sopr ~ 25–50%, Ig.d = 100 W/m2, respectively, are the normalized levels.

Natural and Artificial Lighting

Natural Lighting: Based on the accuracy of visual tasks, [4] states that the coefficient of natural lighting is a controlled parameter. The programmer's work is classified as medium-precision work (visual tasks IV category, minimum object size 0.5-1.0 mm). CPL is fixed at 1.5% when lateral illumination is used.

Artificial Lighting: The lowest illuminance level and the coefficient of light flow pulsation, which should not be greater than 20%, are the specified parameters for artificial lighting. The kind of visual activities is used to determine the minimum illumination. The range for the IV category of visual activities is 300–500 lux.

Production Emissions Electromagnetic Emissions: Table 4.2 shows acceptable levels of non-ionizing electromagnetic emissions from the computer display. The exposure dosage power is the normalized metric for unused X-ray radiation. When the monitor screen is 5 cm away, its level shouldn't go over 100 μR/hour. The programmer's workplace usually has X-ray radiation levels no more than 20 μR/hour.

Table 4.2

Acceptable values for non-ionizing electromagnetic radiation parameters

Parameter Name	**Acceptable Values**
Electric field intensity at a distance of 50 cm from the PC monitor surface	10 W/m
Magnetic field intensity at a distance of 50 cm from the PC monitor surface	0.3 A/m
Intensity for PC operators should not exceed	20 kV/m

Electric field intensity levels may be as high as 6 V/m when 5–10 cm away from the screen and the monitor case, a measurement that is within acceptable bounds.

Static Electricity in Electrical Security: The facilities of the IT department are classified as Class 1, which denotes an area without an elevated danger of electrical shock (dry, dust-free, with standard air temperature, insulated flooring, and a restricted quantity of grounded equipment). The only metal component in the programmer's work area is the computer system unit enclosure, which complies with IBM specifications. As stated in [5], in particular in point 5 on "Measures for Protection Against Static Electricity," grounding the system unit is necessary to counteract static electricity. Nevertheless, investigation revealed that the system unit is not grounded, which is against the recommended guidelines.

The following are the main reasons for electrical shock at work:

– coming into contact with non-conductive metal components, including computer casings, that may be transporting electricity because of damaged insulation;

– using electrical devices without authorization.

Employees are not given enough instruction on electrical safety laws.

Timely action is necessary to address these problems and guarantee a safe working environment for mobile network quality control programmers. To reduce possible risks, regular evaluations and training sessions on electrical safety procedures must be implemented.

4.2. Organizational and Constructive-Technological Measures to Reduce the Impact of Harmful Production Factors

Normalization of Air Quality in Workplaces

An enhanced strategy to normalize the workplace air is presented in order to significantly improve the quality control and management procedures in mobile networks, especially meeting the requirements of 4G and 5G technologies. It is advised to use air filtration technologies, such as HEPA filters, in addition to the current systems for controlling humidity and temperature. This reduces the amount of airborne particles that can harm delicate network equipment in addition to providing programmers with a comfortable working environment.

Lighting for Production

A customized lighting solution is necessary because of the vital nature of the duties involved in the study of quality control in mobile networks. Consider installing smart lighting systems in addition to adding more fixtures. Throughout the day, these systems can dynamically modify color temperature and brightness levels to match circadian cycles. This can improve programmers' visual comfort while also having a good effect on their concentration and productivity throughout long workdays.

Electrical Security

To further enhance electrical safety protocols, it is recommended to incorporate intelligent power management systems. These devices have the ability to track power usage, spot inefficiencies, and instantly improve energy use. In addition to guaranteeing electrical safety, this approach supports sustainability initiatives and is in line with the changing environmental concerns in the field of cutting-edge network technology.

Organization of Workspace and Ergonomics

Buy adjustable furniture and ergonomic devices to further address the ergonomic features of the programmer's workstation. Individual preferences may be catered to with height-adjustable workstations, ergonomic seats, and monitor stands, encouraging a more pleasant and healthful working position. In order to guarantee the team's continued well-being and productivity gains while analyzing quality control and management in the ever-evolving area of 4G and 5G technologies, implement initiatives for routine ergonomic evaluations.

Calculation of the lighting of the workplace of the IT programmer of the airline department for compliance with the degree of visual work

The surface where the programmer's PC is positioned has 200 lux of natural light according to measurement data (luxmeter Yu-116), yet 20,000 lux of open sky illumination illuminates the same area, meaning that KPO = 1% does not match to the normative KPO.

T8 G13 LED lamps are used for artificial lighting in the room. These lamps have several important advantages over fluorescent and incandescent lamps, including: a spectral composition that is similar to natural light; an increased light output (2–5 times higher than incandescent lamps); and a longer service life (up to 10,000 hours) [4].

Using the coefficient of use of the light flux approach, we will determine the artificial lighting for a 40 m2 space that has dimensions of 5 m for width, 8 m for length, and 3.5 m for height.

The method below is used to calculate the necessary number of lamps needed to give a consistent level of lighting. First, we calculate the light flux falling on the work area:

$$F=E*S*K*Z/n. \quad (4.1)$$

Where Z is the ratio of the average illuminance to the minimum (usually taken to be equal to 1.1...1.2, in our case Z=1.1); K is the reserve factor, which accounts for the decrease in the luminous flux of the lamp as a result of contamination of the lamps during operation (its value depends on the type of room and the nature of the work, that are carried out in it, in our case K=1.5); S is the area of the illuminated room (in our case, S=40 m2); The coefficient of usage of the luminous flux, or n, is determined in fractions of a unit and is defined as the ratio of the total flux of all lights to the luminous flux falling on the computed surface. The reflection coefficients from the walls (ρst.) and ceiling (ρceiling), which have values of ρst = 40% and ρceiling = 60%, are characteristics that rely on the lamp, room size, and color of the walls and ceiling.

Let's use this formula to determine the room index:

$$i=S/h(A+B). \quad (4.2)$$

Where S is the room's size, which is 40 m^2; h is the suspension's expected height, which is 3.3 m; A is the room's width, which is 5 m; and B is the room's length, which is 8 m.

We obtain the following after changing the value: i=40/3.3(5+8) = 0.93. With the room index known, we arrive at n=0.22. Enter each value into the following formula to find the luminous flux F:

$$F=(300*1.5*40*1.1)/0.22=90000 \text{ Lm}. \quad (4.3)$$

LED lamps with a matte coating of the LRC-T8-S1500G13-220-22.0W type, the luminous flux of which Fl = 2500 Lm, were used for lighting:

$$N=F/F_{л}. \quad (4.4)$$

Wwhere N is the specified number of lamps; F is the luminous flux, F=90000 Lm; Fl is the luminous flux of one lamp, Fl = 2500 Lm:

$$N=90000/2500=36. \quad (4.5)$$

In the room, lights of the LPO type are employed. There are four lamps in each light. In other words, nine lights totaling thirty-six functional lamps must be used.

The amount of artificial illumination in the airline company's IT department, where the programmer's workstation was examined, does not adhere to hygienic regulations because there are only five lights totaling twenty in each.

4.3. Fire Security

As per [9], the IT department's premises at the airline company's central headquarters fall within category D, which is reserved for "Inflammable substances and materials in a cold state." Locations where GRs are present in the equipment's cooling, hydraulic drive systems, and machinery; where each piece of equipment weighs no more than 60 kg at a pressure of no more than 0.2 mPa; where the equipment's electrical wiring cables are located; and where certain furniture is located on the property.

The IT department for fire safety of building structures is housed in the central office, which falls under category K1 (low fire hazard) due to the presence of non-flammable (safes, various equipment, etc.) and flammable (books, documents, furniture, office equipment, etc.) materials that can burn without exploding when exposed to fire.

Based on its structural attributes, the house can be categorized as a building with load-bearing and enclosing structures composed of concrete or reinforced concrete, natural or artificial stone materials, and ceilings that can be covered with plaster-protected wooden structures or fire-resistant sheet and slab materials.

As a result, the Central Office building's fire resistance level may be categorized as third (III).

Regarding functional fire danger, the aviation enterprise's IT department's buildings are under class F 4.2. Fire-related causes. A fire in the IT department can have very negative outcomes (people dying, important data being lost, property being damaged, etc.). For this reason, it's important to: identify and put out all fire causes; create a plan of action to put out a fire in the house; and arrange for people to be evacuated from the building.

Some of the possible causes of a fire include:

– electrical wiring, sockets, and switches that malfunction and can cause a short circuit or insulation breakdown;

– using damaged or defective appliances;

– using electronic heating devices with open heating elements indoors;

– a fire caused by a lightning strike in the home;

– a fire caused by external influences;

– handling fires carelessly and failing to follow fire safety procedures.

Ways to put out a fire and sound a fire alarm. In line with [9]: "3.3. At each enterprise, taking into account its fire danger, an order (instruction) must establish the appropriate fire-fighting regime, including the following: ... the procedure for organizing the operation and maintenance of existing technical means of fire protection (fire-fighting water mains, pumping stations, fire alarm systems, automatic fire extinguishing , smoke extraction, fire extinguishers, etc.); ..." . The room is equipped with one portable carbon dioxide fire extinguisher (model VVK-5), which is sufficient for this kind of space and kind of room. Moreover, two wireless infrared smoke detectors (IR) Strazh M-501, intended for a 40 m2 space, are mounted on the ceiling.

The fire alarm will sound in the case of a fire, and you should also switch off the electricity, dial 101 for the fire department, leave the building in line with Figure 4.1 evacuation plan, and begin using fire extinguishers to put out the fire. To prevent air access to the object of ignition in the event of a minor fire, makeshift methods might be employed.

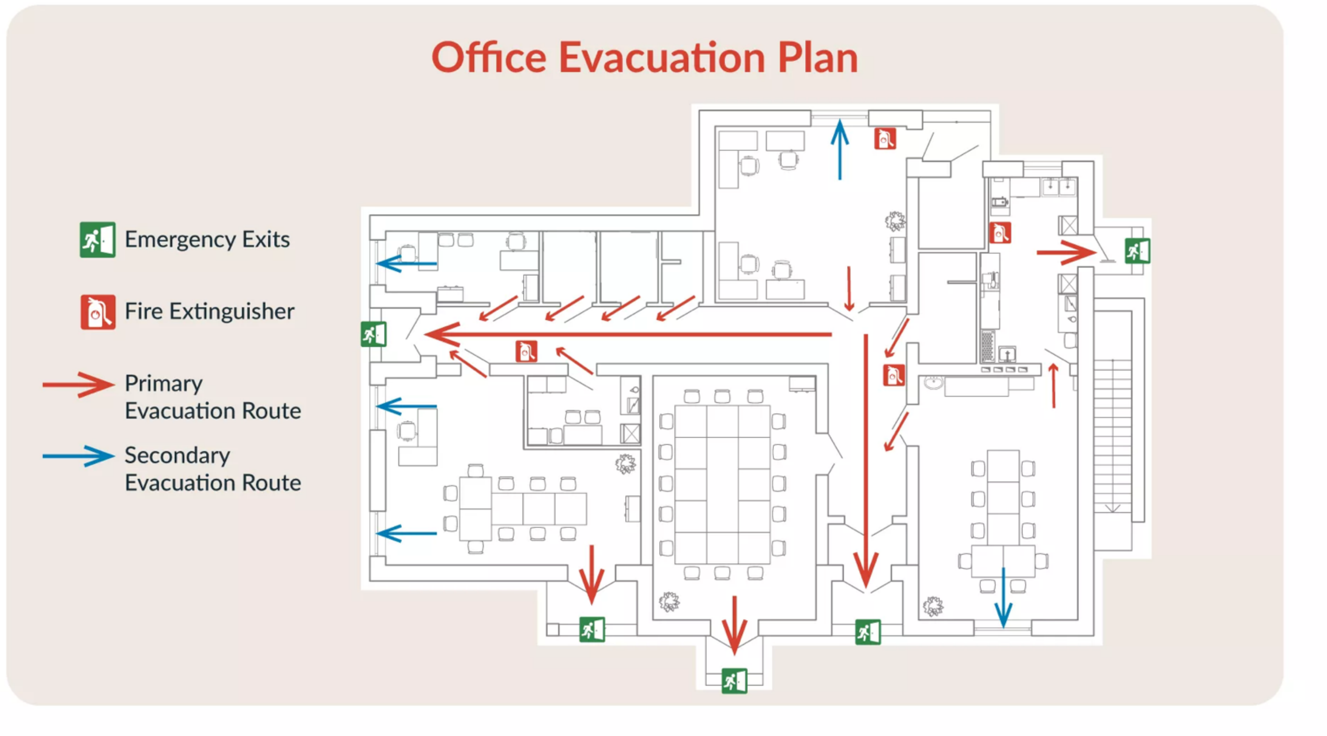


Fig. 4.1. Evacuation plan from the premises of the company's IT department

4.4. Instructions for occupational health and safety when working with a personal computer

General requirements for PC workplace equipment:

1. When using video terminals, an employee's workspace has to be positioned such that windows, lighting fixtures, and reflecting objects are out of their line of sight. The desktop's surface shouldn't be polished. The video monitor screen should be positioned such that light from the window falls from the side, ideally from the left, to reduce glare, especially in the summer and on bright days.

2. The user's (henceforth the operator's) eyes should be at least 500–700 mm away from the PC video display screen. The field of vision ranges from 10 to 40 degrees. The screen's placement perpendicular to the operator's line of sight makes the most sense.

3. The distance between the PC and a heat source should not be less than one meter.

4. The keyboard has to be positioned between 100 and 300 mm from the edge that faces the user, either on the tabletop or on a dedicated stand. The keyboard panel's inclination to the horizontal surface should be between five and fifteen degrees.

5. The table's working surface height should be between 680 and 800 mm.

6. Throughout the work process, the chair should give the user pleasant working circumstances and a posture that makes sense for their body. Height adjustment for the seat surface, backrest angle, and height adjustment should be possible with this chair.

7. Sun protection devices should be mounted on the windows to prevent against direct sunlight, which causes reflections on the video monitor's screen. The video monitor's screen should be positioned such that side light, ideally from the left, enters the workspace from the window.

8. In the rooms where the PC is located, fluorescent bulbs are a good artificial illumination option. Incandescent light bulbs can be used in local lighting installations. At least 400 lux should be present in the horizontal plane workplace illumination at a height of 0.8 meters above floor level. The screen's plane has a maximum vertical illumination of 200 lux. The working surface of the video display and the surrounding area must have a suitably equal distribution of brightness to minimize visual strain.

9. Regular ventilation and daily wet cleaning are required for PC work on the premises during the working day. Dust must be wiped from the screen at least once per day.

10. PC users should wear clothing made of natural materials or a blend of natural and synthetic fibers.

11. Protective screens must be used to shield the operator from electromagnetic radiation and electrostatic fields formed by the video display.

Safety requirements before starting work:

1. The worker must do an exterior examination to verify the system unit housings, video display, printer, and keyboard are in good condition before beginning work.

2. Examine the power cables' structural integrity and the connections between them (mains sockets, extension cords, junction boxes, plugs).

3. Set up your workspace by clearing out everything that could get in the way of getting things done.

4. Switch the PC's power on.

5. The employee is required to alert the management or an information technology professional if, upon turning on the computer, it fails to boot or enter a functional mode.

6. Report any damage or other flaws right once to your immediate supervisor. Never begin working without his permission.

Safety requirements during work:

1. Everything needs to be firmly placed on the table, including the keyboard. It should be possible to move the keyboard at the same time. Its placement and inclination angle ought to accommodate the preferences of the PC user. The keyboard should be placed in the ideal zone of the monitor field, at least 100 mm away from the table's edge, if its design does not allow for space for the palms to rest. Avoid straining when using a keyboard; instead, sit upright.

2. A bigger free area of the table surface should be provided for moving the "mouse" and a comfortable stop for the elbow joint in order to lessen the negative effects of "mouse" type devices on the user (forced posture, the necessity for continual control over the quality of activities).

3. Talking too much, making loud noises, etc., are not permitted.

4. Dust should be periodically cleaned from the equipment's surfaces using a cotton paper napkin that has been gently wet with a soapy solution while the PC is switched off. It is not permitted to use liquid or spray cleaners on PC surfaces. Instead, cotton wool dampened with alcohol is used to wipe the screen and protective screen.

Prohibited:

– individually fix equipment that may have a high voltage (up to 25 kV0) applied to the kinescope and other components;

– placing items on the PC, such as beverages and sandwiches, on top of or close to the keyboard. This can disable it;

– cover the ventilation holes in the equipment, which can lead to its overheating and failure.

Additional regulated breaks are provided for the remaining PC users in order to lessen the detrimental effects on employees' health of various risk factors associated with working on a PC:

– ten minutes following each period of nonstop labor;

– fifteen minutes every two hours.

Try to switch up your activities sometimes to avoid being distracted from your computer job.

It is recommended to utilize alternating text entry and data input operations (varying the content and pace of work) in order to lessen the negative effects of boredom.

When servicing laser printers, keep the following in mind:

1. The printer must be positioned adjacent to the system unit to prevent the connecting cables from becoming stretched. The printer cannot be installed on the system unit.

2. Verify that the printer is in communication mode with the system unit before programming it.

3. Use the paper whose brand is specified in the printer instructions to obtain a high-quality, clear, high-resolution image without damaging the equipment (usually paper weighing 60-135 g/m2, such as Canon or Xerox 4024).

4. To minimize the possibility of paper curling, cut the paper's edges using a sharp knife blade free of burrs.

5. It is best to switch off the video monitor's power while working for longer than 20 minutes or when user interaction in the program's functioning is not necessary.

6. It is essential to complete sets of prescribed exercises for the hands, spine, and eyes during frequent breaks in order to maintain overall muscle tone, avoid musculoskeletal diseases, and alleviate visual pain and other negative subjective experiences.

7. Each person should decide how many micropauses, up to one or two minutes, are appropriate. The structure and substance of breaks might vary, such as eating, exercising as advised, or completing unrelated auxiliary tasks. It is advised that each person exercise during the day, based on how tired they feel. The goals of gymnastics should be to address poor blood circulation, forced posture, partial compensating, and inactivity.

8. As soon as possible, stop working, unplug all devices from the power source, and report any faults – such as sparks, malfunctions, burning smells, burning signs, etc. – to your immediate supervisor or a PC repair expert.

Security specifications for a PC after work:

1. Complete and store the files you were working on in the RAM of your computer. Follow all instructions to ensure that the operating system completes tasks correctly.

2. Switch off the system unit, the printer, and any other attached devices. Turn off any devices that have an uninterruptible power supply (UPS).

3. Press the "POWER" button to turn off the computer, then take the power wire out of the outlet.

4. Use a cover to shield the keyboard from dust accumulation.

5. Establish discipline in the office.

Requirements for safety during emergencies:

1. As soon as possible after turning on the computer, you should unplug it from the power source and notify your supervisor if you smell burning or feel an electric current when you contact any of the metal components of the computer.

2. If there is a fire, use the appropriate fire extinguishing tools to put it out right away. Call the city fire department at 101 to report the incident to the company's DPD chief. Recall that in order to prevent electric shock, electrical systems should be extinguished using dry sand and carbon dioxide fire extinguishers.

3. If someone is hurt at work, stop what you're doing, give them first aid, dial 103 for emergency medical help, and take them to the hospital if needed.

4. Order in which first aid is administered:

5. Assess the extent of the injury, the biggest threat to the victim's life, and the steps that must be taken to save him;

6. Take the necessary actions to save the victim as soon as possible, according to priority: reestablish the patency of the respiratory tract, perform artificial respiration, remove from the contaminated atmosphere, stop burning clothes, etc.;

7. Eliminate the impact of dangerous and harmful factors that threaten the victim's health and life;

8. Call an ambulance or a doctor, or take action to get the victim to the closest medical institution. • Assist the person with basic vital functions until a medical worker arrives.

9. Specific actions to provide first aid to victims of various injuries are described in instruction No. 03-OP "On providing first (pre-medical) medical aid in the event of accidents", which is studied by the company's workers during initial and subsequent training on labor protection issues.

10. In case of other emergency situations, the work should be stopped and the supervisor should be notified.

CONCLUSION TO CHAPTER 4

This section examines the strategies that reduce or eliminate the negative effects of hazardous production elements on the technical personnel of the IT department. The work area's illumination has been calculated. The ideal choice for lighting the work area is represented by the nine lamps with thirty-six LEDs that we got; this option complies with the specified illumination guidelines of 300–500 lux. Guidelines for fire safety in the IT department as well as labor protection instructions for using personal computers were given.

CHAPTER 5
ENVIRONMENTAL PROTECTION

5.1. Analysis of the Impact of Technogenic Factors on the Natural Environment in the Context of Quality Control and Management in Mobile Networks Considering the Requirements of 4G and 5G Technologies

The influence of technogenic variables on the natural environment is analyzed with special attention within the framework of the research on quality control and management in mobile networks. New facets of human contact with the technological environment are brought about by the modern development of mobile technologies, particularly 4G and 5G.

Based on scientific facts, the technogenic environment is characterized by anthropogenic causes and becomes an essential part of the biosphere. This investigation looks at some of the most important features of how mobile network use affects natural ecosystems due to technogenic influences.

Finding out how people interact with the technological environment of mobile networks and making sure that people can live comfortably there are two of the analysis's main goals. Given the rapid pace of technological development, it is critical to assess both the direct effects of technogenic variables and the efficacy of protection measures against detrimental effects on the environment and public health.

Novel technologies that can lessen the negative environmental effects of mobile networks are investigated, and suggestions are made for the creation and application of improved methods for control and management in mobile networks, with a focus on 4G and 5G technology requirements.

5.2. Operation Principles of Base Stations and Cellular Devices and Their Negative Impact on the Environment

In relation to the study "Analysis of Management and Quality Control in Mobile Networks," The issue of the harmful impact of electromagnetic fields produced by base stations and cellular devices in 4G and 5G mobile networks must be addressed, given the requirements of these technologies.

Owing to the exponential growth of technology and gadgets, it is critical to understand that cellular communication base stations and phone handsets are producers of electromagnetic fields. Understanding the effects of these disciplines on the environment and public health requires special consideration.

Because of the location of the station, base stations create impulsive electromagnetic fields that propagate over large distances. Due to the fact that these stations are located in areas where people frequently live, the environment may be constantly impacted.

People constantly come into touch with low-intensity electromagnetic fields that are contained within the radiofrequency spectrum. Experts in hygiene and the environment claim that electromagnetic fields have an impact on health, lowering adaptive reserves, raising the risk of disease, and exacerbating chronic fatigue syndrome.

One important finding is that the installation of base stations in regions where people live regularly requires the adoption of practical steps to reduce the adverse effects on the environment and protect public health. The creation and implementation of technical and preventive measures is necessary to enable the safe and sustainable growth of mobile networks.

Impact at the Cellular Level

Electrical fields have a significant effect on biological structures. EMF-affected charged particles and currents convert field energy into several types of cellular energy. A notable rise in cells with anomalies as a result of exposure to electromagnetic fields is revealed by cytogenetic investigations, such as chromosomal aberration analysis. This suggests possible genetic harm and aberrant hematopoiesis.

Effect on the Tissues

Living tissues experience alterations due to weak electromagnetic fields that are below the threshold for thermal effects. Studies on the biological impacts of cell phones, computers, and other electronic gadgets show that these sources have a deleterious influence on the mechanisms involved in tissue regeneration. Atoms and molecules get polarized under electric fields, which alters their orientation and heats the tissue.

Impact on the Central Nervous System

Direct impacts on the brain, neuron membranes, memory, and reflex actions have been found in experimental investigations on the influence of electromagnetic fields on the nervous system. It has been demonstrated that weak electromagnetic fields can modify the synthesis processes of neuronal cells, changing impulses and perhaps interfering with the passage of information in intricate brain structures. Exposure to high-frequency electromagnetic fields might cause short-term memory problems.

Effects on the Immune System

A growing body of evidence indicates that immunogenic mechanisms are disrupted by EMF exposure. Exposure to electromagnetic fields has been linked to modifications in infection processes, adjustments in protein metabolism, and changes in blood albumin and gamma-globulin levels. Furthermore, electromagnetic fields have the potential to function as allergens, causing allergic people to experience severe responses when exposed.

The Reproductive System's Effects

Under the effect of electromagnetic radiation, spermatogenesis functions less well, menstrual cycles are changed, embryonic development is delayed, congenital deformities occur in infants, and breastfeeding reduces in nursing mothers.

Effects on Plants

Numerous studies show that electromagnetic waves have a major impact on a variety of plant biological processes. Many plant species exhibit notable changes in their morphological, physiological, biochemical, and biophysical properties as a result of both mild and high electromagnetic fields. Reduced dry weight of the above-ground plant mass and possible disturbances in nitrogenase activity in the soil rhizosphere population are among the adverse effects.

Overall Impact on Living Things

Alarming findings come from investigations into the biological effects of computers, mobile phones, and other electronic devices – whether they are turned on or not. These devices have been linked to a number of negative effects on essential biological systems, including diminished biochemical responses, metabolic disruptions, poor tissue regeneration, decreased microbial motility and survival, increased microbial mortality, and lower energy potential.

In summary, knowledge of the complex effects of electromagnetic fields on living things is essential for creating policies and rules that reduce any hazards brought on by the growing use of mobile network technology.

5.3. Methods and Means of Environmental Protection from the Impact of Technogenic Factors

Protective measures against electromagnetic radiation are a specific focus of research on quality control and management in 4G and 5G mobile networks. Given the rapid pace of technological development and the pervasive application of wireless technology, it is essential to protect employee health and mitigate any possible environmental effects.

Defense Against Electromagnetic Radiation

A variety of actions are required to lessen the effects of electromagnetic radiation (EMR) on those who work with radioelectronic equipment and the general public. To ensure environmental protection and safety, organizational, engineering, and medical preventative measures are essential.

Engineering and Organizational Measures

The sanitary supervisory authorities and businesses using EMR sources bear the primary obligation for putting organizational and engineering controls into place. Sanitary laboratories use radiation sources to perform continuous sanitary monitoring of facilities as well as hygiene assessments for new construction and restoration projects. To reduce radiation intensity, it is crucial to pay close attention to how emitting and exposed items are positioned in relation to one another throughout the design process. Precautionary steps also aim to lower the amount of time that employees spend in radiation-prone areas and make sure that radiation sources' power levels comply with national regulations.

Efficiency of Technical and Engineering Methods

Radiation shielding is greatly aided by engineering and technological techniques and tools, such as local, individual, and group protection. The impact can be significantly reduced by use highly directional antennas designed to reduce field intensity and by utilizing natural screens like woods and topographical relief.

The use of radio-protective materials for local protection works incredibly well. Utilizing radio-absorbing materials and metallized textiles guarantees a high level of radiation energy absorption.

Personal Safety Measures

When alternative protective measures are impracticable or inefficient, individuals are outfitted with individual protective equipment, such as eyewear with specific coatings and garments consisting of radio-absorbing materials and metallized textiles. Radio installations may be assured of operational safety through effective control and staff protection.

Diminishing Noise at the Origin

Addressing the source of the noise is one of the best strategies for suppressing it. This entails creating mechanical gearboxes with low noise levels and coming up with ways to make fans and bearing units quieter.

Noise Absorption for Noise Reduction

The loud object is put inside an enclosure with sound-absorbing materials covering the interior walls to reduce the impact of noise radiation. This enclosure needs to be able to absorb enough sound without interfering with the maintenance of the equipment while it's operating or disturbing the inside of the workplace. Using cabins where the loudest object is placed and an employee works is one example of this technique. Instead of just separating the noise source from the rest of the production area, the interior of the cabin is covered with sound-absorbing material to lower noise levels inside.

Sound Insulation for Noise Reduction

This technique entails utilizing sound-absorbing walls or barriers to separate noise-emitting things, or many loud objects, from the main, quieter area. Another way to reduce noise is to place the loudest item in a different cabin. Although the influence of noise is restricted to fewer individuals, the noise levels in the cabin and the isolated space may not reduce. Without lessening the total noise level in the space, screens and caps can help with sound insulation by shielding people from direct sound exposure and safeguarding the workplace.

Using Room Acoustic Treatment to Reduce Noise

To lessen the strength of reflected sound waves, sound-absorbing material is placed on the top portion of the walls and ceiling in rooms with acoustic treatments. The efficiency of acoustic room treatment is increased by adding extras such resonant screens, cones, cubes, and hanging sound-absorbing shields. The volume and geometry of the space, the position of noise sources, the sound-absorbing qualities of the materials and structures utilized, and their arrangement all affect how well an acoustic room treatment works. Low-ceilinged rooms with elongated shapes and ceiling heights no more than six meters are better suited for acoustic treatment. Up to 8 dBA of noise reduction is possible [5].

The design of industrial buildings and equipment should take noise reduction measures into account. Relocating loud equipment to other rooms, minimizing the number of employees in high-noise environments, and putting in place noise reduction strategies with the least amount of money, equipment, and material expenditures should all receive special consideration. All high-noise equipment must be silenced in order to effectively reduce noise.

Making noise spectra and maps of the equipment and production areas is the first step in the noise reduction procedure for a facility's current production equipment. Based on this data, decisions are subsequently taken on the course of the job.

CONCLUSION TO CHAPTER 5

To sum up, the execution of efficient noise management strategies is essential to preserving a secure and comfortable workplace in industrial environments. The solutions covered in this article – which include acoustic treatment of the space, sound absorption, sound insulation, and noise reduction at the source – provide a thorough method of reducing the negative impacts of noise on the surrounding environment and the workforce.

A crucial first step is to address noise at its source by creating low-noise mechanical systems and procedures. This promotes a more peaceful workplace and is consistent with the larger objectives of occupational safety and health.

Applying enclosures and sound-absorbing materials offers workable ways to lessen the effects of noise pollution. These techniques, which reduce direct exposure to excessive noise levels, give workers' well-being priority. Examples of these techniques include enclosing loud equipment or building specialist cabins.

The best way to further improve noise control efforts is to isolate noisy things from the primary working areas. This is known as sound insulation. The focus on isolating noisy sources from the broader workspace guarantees that fewer people are impacted directly, which promotes a more peaceful workplace.

Room acoustic treatment provides a flexible solution by carefully placing materials that absorb sound within a space. This technique improves total noise reduction by taking into account sound wave reflections, especially in areas where certain geometric factors are present.

Industrial facilities must incorporate these noise control techniques into their design from the very beginning, stressing the need to move loud machinery and reduce the amount of workers who are subjected to excessive noise. This proactive strategy guarantees long-term advantages for the firm and its workers, as well as cost-effective implementation.

To summarize, the many approaches covered in this section highlight the importance of a comprehensive and proactive strategy for noise management. Industrial workplaces may provide a safer, more pleasant, and productive climate for all parties involved by implementing these practices.

CONCLUSIONS

In the introduction to this thesis, the problem was clearly defined, and its relevance was highlighted in the context of the rapid development of mobile technologies, specifically 4G and 5G. It was noted that the speed of transition between these technologies and the expansion of services create challenges for quality control and management in mobile networks. The work was aligned with current scientific programs aimed at studying and implementing advanced technologies in mobile networks.

The research goal was identified as the investigation and study of mechanisms for quality control and management in the transition from 4G to 5G technology.

The object of the study modern mobile networks undergoing the transition from 4G to 5G technology. The deployment and integration process of these advanced technologies give rise to challenging situations, becoming the focus of the investigation.

Various research methods, including the analysis of technical aspects, evaluation of the requirements of 4G and 5G technologies, identification of potential problems, and the development of a software product using Python, were employed to achieve the research goal. Thus, based on the chosen approach and methods, a conclusion can be drawn regarding the importance of researching quality control and management in mobile networks, especially during the transitional period between technology generations.

Within the technical analysis, key mechanisms of quality control and management in mobile networks were thoroughly examined. Aspects related to monitoring various network parameters, including bandwidth, delays, and connection stability, were discussed. The main challenges arising from the rapid development of 4G and 5G technologies, such as increased information processing volume and growing complexity of network structures, were identified. Focusing on the transition from 4G to 5G, new features and capabilities provided by fifth-generation mobile technologies were explored. Significant increases in bandwidth, faster data transmission speeds, and widespread Internet connectivity for various devices were identified. An overview of technical solutions implemented to support new features in the context of quality management in 5G networks was provided.

This analysis of technical aspects serves as the foundation for further research and the development of quality control and management strategies in mobile networks adapted to the requirements of current and future communication technologies.

At this stage of the research, the requirements imposed by 4G and 5G technologies on quality control systems in mobile networks were thoroughly studied and analyzed. Parameters such as data transfer speed, connection reliability, delays, and massive device support were considered. Special attention was given to new requirements arising from the increased volume of processed information and the emergence of new opportunities in 5G networks. The unique opportunities offered by 4G and 5G technologies for optimizing quality control were thoroughly analyzed. Specifically, scalability, high bandwidth, low latency, and other characteristics defining the advantages of new standards were examined. The study also explored how these features impact the requirements for quality control systems and service quality for end-users.

The obtained results regarding the requirements and features of 4G and 5G technologies constitute a key contribution to understanding the need for adaptation and optimization of quality control systems for the effective utilization of new capabilities in mobile networks.

The development of the software product involved choosing the Python programming language due to its flexibility, a wide range of libraries, and a large developer community. Python allows efficient interaction with various data sources and rapid implementation of diverse functionalities. The developed software product is a chatbot that interacts with users through the popular messenger platform, Telegram. Its main purpose is to provide timely and convenient information to users about key parameters of mobile networks, especially those affecting service quality.

The research results represent a significant contribution to the development of modern mobile networks. The developed quality control and management strategies, as well as the software product for timely user information, can improve service quality and resource efficiency during the transitional period from 4G to 5G. The assessment of requirements and unique capabilities of 4G and 5G technologies enabled the development of adapted strategies that consider the specificities of new standards.

Despite the achieved results, it is crucial to emphasize that the field of quality control and management in mobile networks is dynamic and constantly evolving. Possible directions for further research include expanding the functionality of software products, improving data analysis algorithms, and exploring the impact of new technologies, such as artificial intelligence and the Internet of Things, on quality control in mobile networks.

In conclusion, this study opens perspectives for further exploration and development in the field of mobile network management, considering the high service quality requirements in the era of 5G.

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