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Fifth Generation Fixed Network (F5G)
F5G High-Quality Service Experience Factors
Release #1

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Reference

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Foreword

This Group Specification (GS) has been produced by ETSI Industry Specification Group (ISG) Fifth Generation Fixed Network (F5G).

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

The present document studies the end-to-end Quality of Experience (QoE) factors for services over the broadband network. High-QoE reflects the overall performance at the service level from the perspective of the end user. The present document analyses the general factors that impact service performance and identifies the overall high-QoE dimensions for each service. The key services discussed in the present document are typical Internet applications and Virtual Reality (VR). Other services and applications QoE are for further study.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

[1] ETSI GS F5G 004: "F5G Architecture Release 1".

[2] Recommendation ITU-T Y.1540: "Internet protocol data communication service - IP packet transfer and availability performance parameters".

[3] Recommendation ITU-T P.863: "Perceptual objective listening quality prediction".

[4] ETSI TS 103 222-1: "Speech and multimedia Transmission Quality (STQ); Reference benchmarking, background traffic profiles and KPIs; Part 1: Reference benchmarking, background traffic profiles and KPIs for VoIP and FoIP in fixed networks".

[5] ETSI TS 103 222-2: "Speech and multimedia Transmission Quality (STQ); Reference benchmarking, background traffic profiles and KPIs; Part 2: Reference benchmarking and KPIs for High speed internet".

[6] Recommendation ITU-T J.247: "Objective perceptual multimedia video quality measurement in the presence of a full reference".

[7] IETF RFC 3357: "One-way Loss Pattern Sample Metrics".

[8] IETF RFC 768: "User Datagram Protocol".

[9] IETF RFC 3550: "RTP: A Transport Protocol for Real-Time Applications".

[10] IETF RFC 793: "Transmission Control Protocol".

[11] Recommendation ITU-T P.10: "Vocabulary for performance and quality of service".

[12] Recommendation ITU-T G.988: "ONU management and control interface (OMCI) specification".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TR 102 505: "Speech and multimedia Transmission Quality (STQ); Development of a Reference Web page".

[i.2] ETSI EG 202 057 (Part 1 to 4): "Speech Processing, Transmission and Quality Aspects (STQ); User related QoS parameter definitions and measurements".

[i.3] Broadband Forum (BBF) TR-126: "Triple-play Services Quality of Experience (QoE) Requirements".

[i.4] ETSI GR F5G 002: "F5G Use Cases Release 1".

[i.5] ETSI White Paper No. 47, "Fibre Development Index: Driving Towards an F5G Gigabit Society", ISBN No. 979-10-92620-41-1.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the terms given in F5G Architecture [1] and the following apply:

Key Quality Indicators (KQI): QoS metrics, which are important and have a major impact on the QoE of applications and networks

Mean Opinion Score (MOS): mean of the values on a predefined scale that users assign to their opinion of the performance of a system quality

NOTE: See Recommendation ITU-T P.10 [11].

Quality of Experience (QoE): subjective measure of performance of applications or services that relies in human opinion on the perceived quality

Quality of Service (QoS): description or quantitative measurements of the overall performance of the F5G system at the network, service, and application domain

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in F5G Architecture [1] and the following apply:

AP	Wi-Fi® Access Points
Cloud VR	Cloud Virtual Reality
DRTT	Downstream Round-Trip Time
DSLR	Downstream Segment Loss Rate
FoV	Field of View

KQI	Key Quality Indicators
MOS	Mean Opinion Score
NPS	Net Promoter Score
USLR	Upstream Segment Loss Rate
VoD	Video on Demand

4 Introduction

4.1 Overview of High-Quality of Experience (QoE)

This clause provides an introduction to Quality of Experience (QoE) and the distinction between QoE and QoS as used in the present document.

The QoE (Quality of Experience) and QoS (Quality of Service) terminology (see clause 3.1 for the term) are often used interchangeably, but are actually two separate concepts.

The QoE is a combination of objective measurable components (as metrics on the conditions in the network and service platforms that are required for a specific service to work properly) and subjective components (as user expectancy on the service, user previous experience or user personal preferences).

Mean Opinion Score (MOS) is one often used QoE measurement metric typically used to quantify the perceptual impact (the users' QoE) for various forms of service degradation.

QoE can also be assessed based on objective QoS metrics. There are different QoS metrics, which can be gathered, some easy to collect other more difficult. Depending on the specific service different combinations of these metrics may be needed for QoE assessment. The availability and understanding of these QoS metrics determine QoE assessment in different levels of detail. This QoE assessment based on QoS metrics is the focus of the present document.

QoS is a measure of the performance of networked services at the network or application level. QoS also refers to a set of techniques that enable the network administrator to manage the network performance differentiating between different users. QoS metrics may include network layer measurements such as packet loss, delay or jitter or application level measurements such as video frame loss, frame freezing, image distortion. The Key Quality Indicators (KQI) are the QoS metrics, which have the largest impact on QoE.

In general, there is a non-linear relationship between the subjective QoE as measured by the MOS or other metrics and various parameters used to measure network performance (e.g. encoding bit rate, packet loss, delay, availability, etc.).Typically there will be multiple service or network level performance (QoS) metrics that will impact overall QoE. The relationship between QoE and service and network performance (QoS) metrics is typically derived empirically. Having identified the QoE/QoS relationship, if it is possible, it can be used to predict the expected QoE for a user, given the QoS parameters, or given a target QoE, the required network and service requirements can be derived.

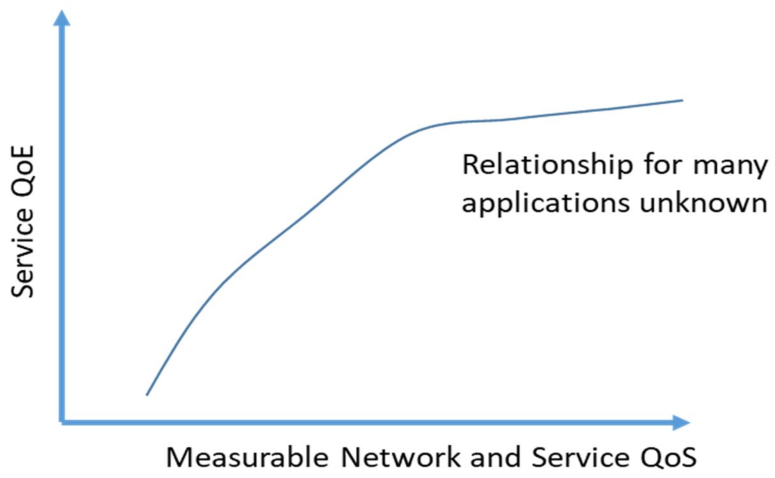

Figure 4-1: Example QoS/QoE non-linear relationship

The Key Quality Indicators (KQI) are composed by the QoS metrics, which have the largest impact on QoE, namely user centric and service specific quality patterns that directly influence the user perception for each service category. The definition of these quality patterns poses a challenge where Artificial Intelligence correlation techniques may play an important role.

QoE targets are needed for each service and application and should be included from the beginning in system design and engineering processes where they are translated into objective service level performance metrics.

QoE requirements shall be considered from a complete end-to-end system perspective. All end-systems (client and servers), application services and networks (nodes, links) that can contribute to the user experience using a service shall be taken into account. But also several stakeholders are contributing to a high end-to-end QoE. Those include the network service provider, the application provider, and the server/client device providers among others.

QoE-oriented engineering includes processes to analyses user requirements, derive measurable parameters, having the different configuration aspects of the components in the end-to-end service delivery chain, and identify the relationship between the measurable parameters and the subjective user quality of experience.

Quality of Experience is an important factor in the success of F5G services and is expected to be a key differentiator with respect to competing service offerings. Subscribers to network services and applications are increasingly sensitive to how well a service meets their expectations for performance, operability, availability, and ease of use.

4.2 Structure of the present document

User assessment of application and service quality has some subjective aspects, however the present document focuses on QoE assessment based on measurements. These measurements are made at network and at application level.

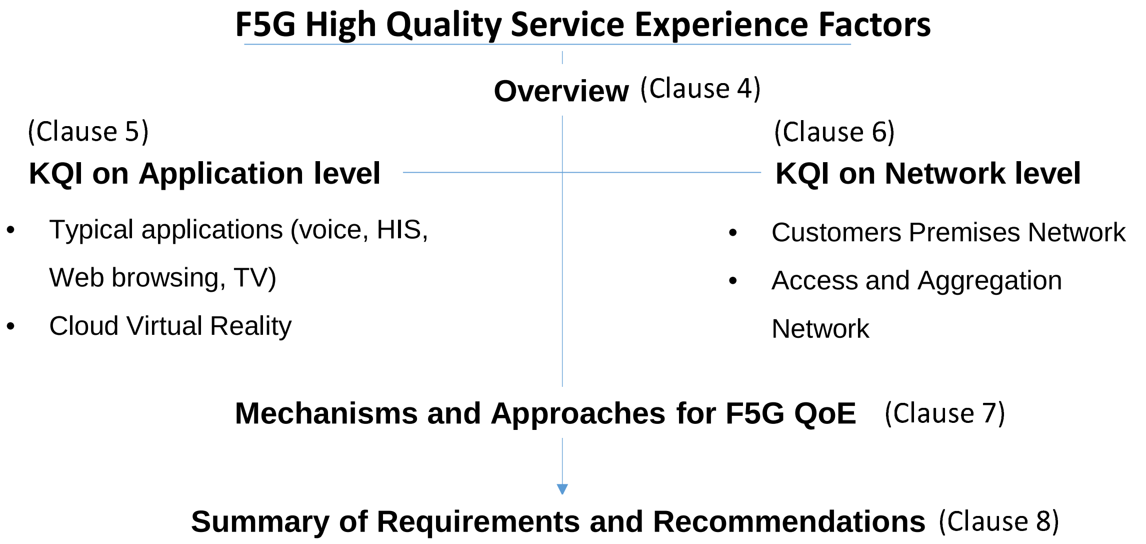

Figure 4-2: Structure of the present document

The present document is structured as follows:

- Clause 5: Specification of the measurable Key Quality Indicators (KQI) on the application level (typical applications by referencing the appropriate specifications and Cloud VR as a new application with new sets of KQIs enabled by F5G).
- Clause 6: Specification of the measurable Key Quality Indicators on the network level in the different segments of the network.
- Clause 7: Specification of different mechanisms and approaches to either measure or improve QoE. Several measurement approaches for key performance indicators and QoE assessment methods are specified and the use of novel concepts like network slicing and AI-based QoE assessment are described.
- Clause 8: Finally, the present document is summarizing the requirements and recommendation for a F5G QoE.

5 Application Services and related QoE factors

5.1 QoE of Typical Applications

5.1.1 General Description

In the present document, the term typical application is used for applications that are well established, which have standardized quality metrics. These applications include Voice, High-speed Internet, Web browsing, and TV.

The Key Quality Indicators for the typical applications considered are not described in the present document, but existing specifications are referenced.

5.1.2 QoE Factors of Typical Applications

5.1.2.1 Introduction

QoE factors are described by various standardization organizations. In the following clauses only a few specifications examples are given in order to refer to existing work in the area of QoE for well-known applications.

5.1.2.2 Voice

A list of voice application QoE factors are described in Recommendation ITU-T P.863 (POLQA) [3] and ETSI EG 202 057 (Parts 1 to 4) [i.2]. The key performance indicators for voice services are described in ETSI TS 103 222-1 [4].

5.1.2.3 High-speed Internet

ETSI EG 202 057 (Part 4) [i.2] shows key performance indicators for the High-speed Internet Service and ETSI TS 103 222-2 [5] the QoS parameters for the High-speed Internet service.

5.1.2.4 Web Browsing

For web browsing application many of the parameters for high-speed internet apply, however, for testing purposes there is also a reference standard for a web page with reference content as defined in ETSI Kepler Reference Web-page [i.1]

5.1.2.5 TV

For perceived video quality, Recommendation ITU-T J.247 [6] shows a set of parameters. For the user interface of TV services, IETF RFC 3357 [7] defines One-way Loss Pattern Sample Metrics. Finally, the overall triple play service QoE requirements are shown in BBF TR-126 [i.3].

5.1.3 Generic Measurement Methodology

The measurement of QoE parameters is typically performed through emulation of the full application with client and servicer running over a network under test. This requires having the test systems, application client and server, which are located at different positions in the network under test. The QoE is measured at the client application user interface. The results of these QoE measurements show a level of QoE in a particular situation. However, it is difficult to generalize these results, since they depend on the location of the clients and application servers and they depend of the actual traffic in the network under test.

For other applications, the measurements are performed by emulating an application client, using a real implementation of the application server. Again that runs over a network under test, but also using an application server under test. For performing these measurements, the location of the application client and application server matters. Furthermore, the traffic of other users in the network and/or users using a particular application server matters.

Finally, the content of the application might have an impact on the measurement. For some applications there exists sample content in order to receive comparable measurement results.

5.1.4 Generic QoE management

QoE management can generically have two approaches:

- The network is dimensioned to ensure that the applications quality requirements are fulfilled. QoE depends on the network characteristics.
- The applications adapt to the QoS of the network to achieve the best possible QoE. This includes managing the applications in terms of capacity, response times and other parameters.

This is particularly difficult, since different applications are running on the same network and therefore compete for the same resources, and the services and network resources to be used are difficult to know in advance. In a few cases the applications can be modelled and network configuration parameters can be derived. But in many cases, the QoE needs to be assessed and re-configurations of the network maybe required to improve the QoE.

5.2 Cloud VR

5.2.1 General Description

Cloud VR is a new application enabled by F5G networks and therefore the Key Quality Indicators of Cloud VR are described in the following clauses, addressing different use cases.

Cloud VR is a new cloud computing technology for VR services, which includes VR video, VR gaming, and VR industry applications, providing an unprecedented level of immersive experience for users. However, these Cloud VR services require extremely large bandwidth, low latency, and low packet loss rate, which is a huge challenge for the network. The large-scale deployment of Cloud VR services requires the joint effort from the industry partners to address E2E quality management and monitoring. Cloud VR is an ever expanding services area and are for further study.

Local rendering requires expensive high-performance devices to provide acceptable user experience. Fast and stable transport networks enable VR content to be stored and rendered in the cloud, and video and audio outputs are coded, compressed, and transmitted to the user terminals. With Cloud VR, users enjoy VR services without having to purchase expensive hosts or high-end PCs, promoting VR service popularity. Cloud VR services are further classified as having strong or weak interaction:

- Weak-interaction VR services: Full-view video, VR live broadcast, IMAX® theatre
- Strong-interaction VR services: VR games, VR home fitness, VR education, and VR social networking

NOTE: In the following, the focus is on a subset of VR services, but many of the key indicators can be generalized for other VR services and applications of a similar type.

5.2.2 Factors Affecting Cloud VR service

5.2.2.1 Factors Affecting Weak-Interaction Cloud VR Service Experience

Different transmission solutions have different factors affecting user experience. For the weak-interaction Cloud VR services, Cloud VR video has two transmission solutions.

a) Cloud VR Full-view Transmission solution

The full-view video transmission solution is widely adopted at the initial stage of service development. In this solution, the streaming media server transmits all 360-degree video content to the user terminal, which is responsible for tracking the user head motion as well as decoding and displaying locally cached video data.

Table 5-1: Full-view QoE Indicators

Service	Experience Indicator	Evaluation Indicator
Full-view Video	Initial buffering	Initial buffering duration
	Frame freezing	Average percentage/duration of frame freezing
		Number of freeze frame occurrences

Initial buffering

As with traditional online video, after the user clicks the Cloud VR video play button, there is a loading process for performing CDN scheduling, index downloading, and data caching. For this process, users generally only see the loading progress bar. The shorter the loading time, the sooner the user sees the video content and the better the experience.

Key Quality Indicators

- **Initial buffering duration:** Is the time from when the user clicks the Cloud VR video play button to when the user sees the normal play screen.

Frame freezing

During full view VR video playing, if the downloaded data is exhausted by the player and it cannot meet the real-time playing requirements, the terminal will choose to stop playing first and it will wait until the newly buffered video data reaches a certain level, then restart playing. The phenomenon of buffering and playing after stopping is called a freeze frame.

Because it will interrupt the user's viewing process, it has a greater impact on the user's experience. In general, the lower the number of freeze frames and the shorter their duration, the better the user's experience.

Key Quality Indicators

- **Average duration of frames freezing:** Is the average of multiple freezing time per time window during VR video playing.

- **Average percentage of frames freezing:** Is the ratio of the total freezing time to the total playing time per time window during VR video playing.

- **Number of frames freezing:** Is the number of frames freezing per second during VR video playing.

b) Cloud VR FoV Transmission solution

In contrast to the full-view transmission solution, the Field of View (FoV) transmission solution only downloads and plays the high-definition images within the user viewing angle. Although the FoV transmission solution is far less demanding on the terminal's decoding performance and network transmission bandwidth, it poses new requirements on service experience.

Table 5-2: FoV Video Indicators

Service	Experience Indicator	Evaluation Indicator
FoV Video	Initial buffering	Initial buffering duration
	Frame freezing	Average percentage/duration of frame freezing
		Number of freeze frame occurrences
	Low quality image display	Average percentage of the low quality image area
		Percentage of low quality image duration

For the Initial buffering and Frame freezing of FoV video, the experience indicators and evaluations indicators are the same defined for full-view service.

Low quality image display

In the Cloud VR use case of ETSI GR F5G 002 [i.4], the VR video source file is divided into multiple segments for storage in the cloud. Each segment corresponds to a different FoV. Based on the head motion of the user, the terminal locally calculates the current FoV. The terminal requests the corresponding high-definition segment. The cloud server responds by sending the requested segment and a low-definition full-view background video. The terminal displays the high-definition segments when available and fills the remaining portion of the screen with background video.

If these dynamic processes suffer network or application delay, the user will only see low-definition content.

Key Quality Indicators

- **Average percentage of the low quality image area:** is the average value of the low-definition content in the user's viewing area during the playing process.

- **Percentage of low quality image duration:** is the proportion of playing time of low-definition content during the playing process.

5.2.2.2 Factors Affecting Strong-Interaction Cloud VR Service Experience

With strong-interaction Cloud VR services, users experience real-time interaction with cloud applications through terminal sensors. After performing calculation, rendering, compression, and encoding on an interaction instruction, the cloud application servers send response images as video streams to the user's terminal for decoding and display. For strong-interaction Cloud VR services, Cloud VR gaming is currently the most demanding service and is taken as an example. Other strong interaction services might have similar key indicators.

Table 5-3: Game Indicators

Service	Experience Indicator	Evaluation Indicator
Game	Frame freezing	Average percentage/duration of frame freezing
		Number of freeze frame occurrences
	Black edge (Head motion)	Average percentage of the black edge area
		Percentage of the black edge duration
	Operation response latency	Average response duration

Frame Freezing

The frame freezing indicators are the same as the video frame freezing indicators.

Black edge (Head motion)

Black edge and smearing: to save cloud rendering resources and shorten E2E latency, Cloud VR gaming servers generally only render and transmit images within the user's view angle. Therefore, the new viewing areas that are not rendered on time are displayed as black edges or smearing. The faster the head motion, the longer the cloud rendering and streaming latency, and the more pronounced the black edge and smearing are.

Key Quality Indicators

- **Average percentage of the black edge area:** is the average value of the black edge / smearing in the user's viewing area during the game.

- **Percentage of the black edge duration:** is the proportion of the time duration with black edge effect to the total time duration of the game.

Operation response latency

In strong-interaction application scenarios, such as Cloud VR gaming, users expect immediate audio-visual responses when they move horizontally, pull a trigger, or wave a hand. If the response takes longer than they expect, they experience interactive latency. Operation response latency is caused by the asynchronous collaboration between the cloud rendering and streaming process and the local playout process.

Key Quality Indicators

- **Average response duration:** is the average time from the action of the user detected by the terminal to the corresponding game screen display.

5.2.3 Measurement Methodology

The key indicators described above are measurable on the end-system of the application. QoE is assessed based on that application QoS measurements. The QoE assessment uses either some heuristics or some subjective tests to assess the perceived QoE. The detailed assessment of QoE based on the measured key indicators is for further study.

5.2.4 QoE Management

There are various ways of dealing with degraded key indicators. First, the application can trade certain key indicators against others. For example, the resolution, which might have a lower impact on QoE than freeze frames or black edges, can be adapted to the available bandwidth. Details are for further study. Second, the network QoS of such application session can be improved by the collaboration of the application with the network provider's QoS management system. Finally, the dimensioning of the Cloud VR slice might need to be adapted to have less frequent QoE impacting events.

6 Factors impacting QoE for Networking Services

6.1 Customer Premises Networks

6.1.1 General Description

The following clauses describe the Quality of Experience aspects and related issues for broadband services. The focus is only on the on-premises part of the end-to-end F5G network that is an essential factor for user experience. The Quality of Experience factors related to operator network are described in clause 6.2.

With the F5G Access and Aggregation Network enabling higher speeds and lower latency to the customer premise, the on-premises network shall be able to cope with new demanding services and higher than usual traffic loading. This clause assumes a scenario of broadband services, where a worse than expected QoE is affecting customer churn rates, increased operator's touch-point interactions, decreased customer satisfaction, and decreased brand image.

6.1.2 QoE Factors for CPNs

On-premise networks or Customer Premise Networks (CPN) are based on different technologies, different business models, and different customer requirements. Therefore, only the key factors impacting QoE are described.

Wi-Fi is one of the most popular solutions used in on-premises networks and therefore factors impacting the QoE that are related to the Wi-Fi and other CPN technologies are considered.

Factor: Coverage

Coverage of a radio station is the geographic area over which the station can communicate. In the context of on-premises service, the geographic area is the premises itself. Customers expect a good and full coverage of their premises. This means the customer devices communicate with a certain bandwidth.

The coverage in this context is defined as the ratio of the geographic region having connectivity and the total geographic size of the premises.

Factor: Application-dependent Coverage

The definition of coverage might be ambiguous, since coverage can be application dependent (e.g. low bandwidth applications like chat and e-mail might work while others do not). However, coverage can also be defined as giving the end-system good enough connectivity to enable applications to have good QoE, including demanding applications like Cloud VR, Video, etc. Therefore, application-dependent coverage means the customer benefits of a satisfactory use of all the application on-premises.

In case of a Wi-Fi on-premises network, repeaters are often used, additional Wi-Fi Access Points (AP) with wired backhaul, or a Wi-Fi mesh solutions to minimize these problems. So QoE management also applies to these tools.

Factor: Wi-Fi Interference in unlicensed spectrum

In dense areas, it is common to be in the reach of several APs generating high levels of interference. Using the latest technologies for interference avoidance, the use of the 5 GHz band or, in the near future also the 6 GHz band, helps to minimize the problem, but the number of reachable APs in the neighbourhood continues to grow.

Factor: Bandwidth

When subscribing to a broadband fibre connection, which is advertised as having a large available bandwidth, customers expects to benefit from that bandwidth in their devices. Very often, customers use speed test tools to check if they receive the bandwidth mentioned in their subscription. However, since usually several devices are connected through Wi-Fi and share the CPN, performance might not correspond to the contractual performance. This leads to misunderstandings and creates the perception that the operator is selling a poor service.

In multi-AP scenarios, the choice of the AP by the device can affect the bandwidth available to the device and naturally other connected devices share the overall system bandwidth. Also in multi-AP scenarios the backhaul of each AP plays a more important role than in a single-AP deployments. The deployment of Fibre-To-The-Room (FTTR) [i.4] solves the backhaul issue due to better quality and higher bandwidth fibre backhaul. In the case of wireless backhaul of the AP, the backhaul links need to be properly managed (see below for QoE management). In the case, the network decides the AP to which a device connects. This choice impacts the QoE. Appropriate algorithms for choosing the APs are required which shall take into account the context like radio propagation, location of AP, etc. and the load of the CPN.

Factor: Connection Stability

Varying speed, short interruptions, multi-media quality problems, which are not caused by the server or the network beyond the CPN, but all these issues generate user complains even though it is in the customers domain.

Maintaining connection stability during device mobility within the coverage of the CPN is important for some applications.

Specifically, in multi-AP scenarios, the choice of the AP by the device and the AP to AP handover might cause some short interruptions or bad quality. In multi-AP scenarios, where the backhaul is also wireless, connection stability issues might multiply since traffic runs over more than one wireless links before it enters the fixed network.

Factor: Security and privacy

Security and privacy are very difficult to measure and it is very difficult to explain to non-experts, which most customers are. On the other hand, one of the criteria to choose a service from a certain service provider is based on the perceived security and privacy this service provider is able to provide. This applies to all levels, not only the Internet service, but also the application itself, which might be out of the control of the service provider.

In addition, an automatic or easy and understandable configuration of security on the devices and CPN nodes may create a good user experience.

6.1.3 Measurement Methodology for CPNs

Measuring QoE is a difficult challenge since it is based on a subjective perception from the users. It is influenced by a wide variety of application depended factors (such as the users environment and connection characteristics). There is no direct and simple way to measure QoE. It should be possible to estimate QoE indirectly based on the measurement of several parameters.

Measurements based on network information

In the on-premises network equipment, several parameters are measured and monitored, which can indicate QoE problems. These include whether packets to a particular device are transmitted, whether there are Wi-Fi errors, or whether many re-transmissions or FEC errors occur on the different level of the protocol stack.

Also, in the case where application traffic is not encrypted, the traffic can be analysed, to derive information of issues at the application level.

Measurements within the application

The measurements point in the application protocol stack might detect issues, such as multimedia errors, etc., which can give hints to CPN QoS problems impacting user experience.

Measurements based on User Behaviour

Since users tend to have similar reaction when experiencing similar QoE problems, therefore user behaviour provides critical data on QoE problems. For example, users frequently using a speed test application implying that they may not be happy with the service.

6.1.4 QoE management for CPNs

Several techniques to estimate QoE are possible, enabling actions to be taken to increase the user's experience.

In many cases, the wireless part of a connection is the most problematic and, therefore using wireline connections is a better solution for QoE in terms of networking. However, users usually prefer the convenience of mobility for their devices and avoiding wiring problems and a wireless solution should also be available.

In order to take advantage of the high-bandwidth enabled by F5G deployment, the combination of fibre to the room together with a Wi-Fi AP is an improvement of coverage, since the Wi-Fi APs serves a restricted area (e.g. the room) on low power, minimizing interference problems. Through the short distance between end-user device and AP, high-bandwidth is achieved.

Wi-Fi APs can implement QoS features for certain traffic, in these cases the application shall be identified and the right service classes in the CPN shall be chosen. In multi-AP scenarios, this functionally is performed on each AP or coordinated over the whole CPN. The coordination of multi-AP systems shall be QoS aware.

Measuring the Wi-Fi quality indicators in the APs help to identify potential problems with device connectivity quality. It might be possible to solve some of the problems by changes in the Wi-Fi configuration, but other problems may require interaction with the customer, for example, locating a Wi-Fi AP at a different place or adding an additional AP.

The potential measures to be taken in case of bad QoE should be detected and corrected automatically. Some of those functions benefit from AI functionality to learn and improve quality.

6.2 Access and Aggregation Network

6.2.1 General Description

According to the F5G architecture [1] the network service is provided between Service Access Points (SAPs). Many of these services cross the access network and the aggregation network segments. Therefore, the present clause handles access and aggregation network together. Though there might be domain specific issues, in general the assumption is that the networking part is very similar. In the aggregation network there are different networking fabrics possible, and therefore the Underlay Plane technology might be different.

In Clause 5, several applications and their QoE factors are listed, however from a networking perspective there is no direct knowledge about the application. Therefore, QoE in networking can only be addressed from a data traffic perspective and some clues are derived from that.

In the case where the network is aware of the application, then the network can address QoE for those applications to a certain degree, based on the application layer information accessible by the network nodes and can derive application specific QoE parameters. However, many applications are difficult to detect due to end-to-end encryption of application traffic and due to regulatory limitation in monitoring application level information in certain geographic regions.

The major factors influencing QoE on the network level are described in the following clauses.

6.2.2 QoE Factors for Access and Aggregation Networks

6.2.2.1 Bandwidth

In general many applications perform better with higher bandwidth. So the bandwidth available and usable by the applications has a major impact on the QoE. With the migration from F4G to F5G a much higher bandwidth is available in the Access Network through XG(S)-PON and the Aggregation Network through next generation IP/Ethernet and OTN technologies, however that bandwidth is shared among several users and applications.

In the F5G Access Network, the deployed PON technology and ODN splitting ratio are the major factors determining the amount of shared bandwidth per user and application.

The major factor impacting user bandwidth is the statistical multiplexing of user traffic in the IP Aggregation Network.

6.2.2.2 Latency

In general lowering latency improves the QoE for many applications (such as Cloud VR). However, for applications the end-to-end latency, terminal to terminal or terminal to application server, matters. The two segments, Access and Aggregation, contribute only a proportion of the total latency, but many times an important part.

The applications most affected from latency are interactive and transaction oriented applications, since the communication pattern is request-reply.

6.2.2.3 Packet Jitter

In general the lower the packet jitter is, the better the application performance. A typical mechanism for applications to deal with packet jitter is turning it into higher latency through buffering or similar mechanisms before the end-users notice the effects, however this has an impact on users experience as they have to wait for the buffering or caching to be completed before accessing the content.

6.2.2.4 Reliability

The duration of a network connection interruption has an effect on QoE.

6.2.2.5 Security

In general, security has so far not been regarded as an indicator for assessing QoE, since the perceived quality of a user is more influenced by performance oriented quality indicators.

Most users cannot assess security, but they have some perception of whether a service or application is secure. The application can present a security indication that the application is secure. Whether and how security is impacting QoE is for further study.

6.2.3 Measurement Methodology

6.2.3.1 End-to-end Measurements

Recommendation ITU Y.1540 [2] defines the measurement methodology on the IP layer between two measurement points. Many of the factors impacting QoE, as described above, are measured. Even if the impact of each factor on QoE is difficult to derive, the measurement guides further development of the network, since any improvement in these metrics favours an improvement of QoE as well.

6.2.3.2 Network Telemetry

A set of parameters impacting QoE is measured in the network by monitoring the service flows and exporting this information to the telemetry systems through a dedicated interface. Based on that information the effect on QoE is assessed. ETSI ISG F5G is defining such a telemetry system in further studies.

6.2.4 QoE management

6.2.4.1 Network Planning

The planning of the physical network, specifically the split ratio of the ODN P2MP tree, influences the bandwidth offered to the end-user. The redundancy of nodes and links impact the reliability of the network services.

6.2.4.2 QoS management

QoS management of the Access and the Aggregation Networks shall ensure a reliable and high quality network, which will have a positive impact on the QoE.

7 Mechanisms and Approaches for F5G QoE

7.1 General Considerations

In general various approaches for QoE management can be used. A basic non-technical approach is the survey of customer satisfaction of a network services with the customers of that particular network service. This includes not only the aspects of the network performance, but also other aspects of the interaction of a service provider with its customers (e.g. by measuring Net Promoter Scores (NPS)).

Also the improvement of QoE for the migration from copper based networks to fibre based networks are measured on a high level by correlating customer satisfaction survey results (e.g. NPS) for users of copper-based network services with those for fibre-based network services [i.5].

User assessment of application quality has some subjective aspects, however the present document focuses on QoE assessment based on measurements.

7.2 Measurement-based QoE Assessment

7.2.1 Introduction

Figure 7-1 illustrates a simplified end-to-end system that is used to classify and discuss the different mechanisms and approaches for measuring and assessing QoE. The system is partitioned into user and service provider domains, and it is separated into the network layer and application level.

The QoE assessment is based on measurements made at different locations of the network, both at network and at application level. Figure 7-1 shows users on both ends of the system. However, many cloud-based services would be from user to an application server.

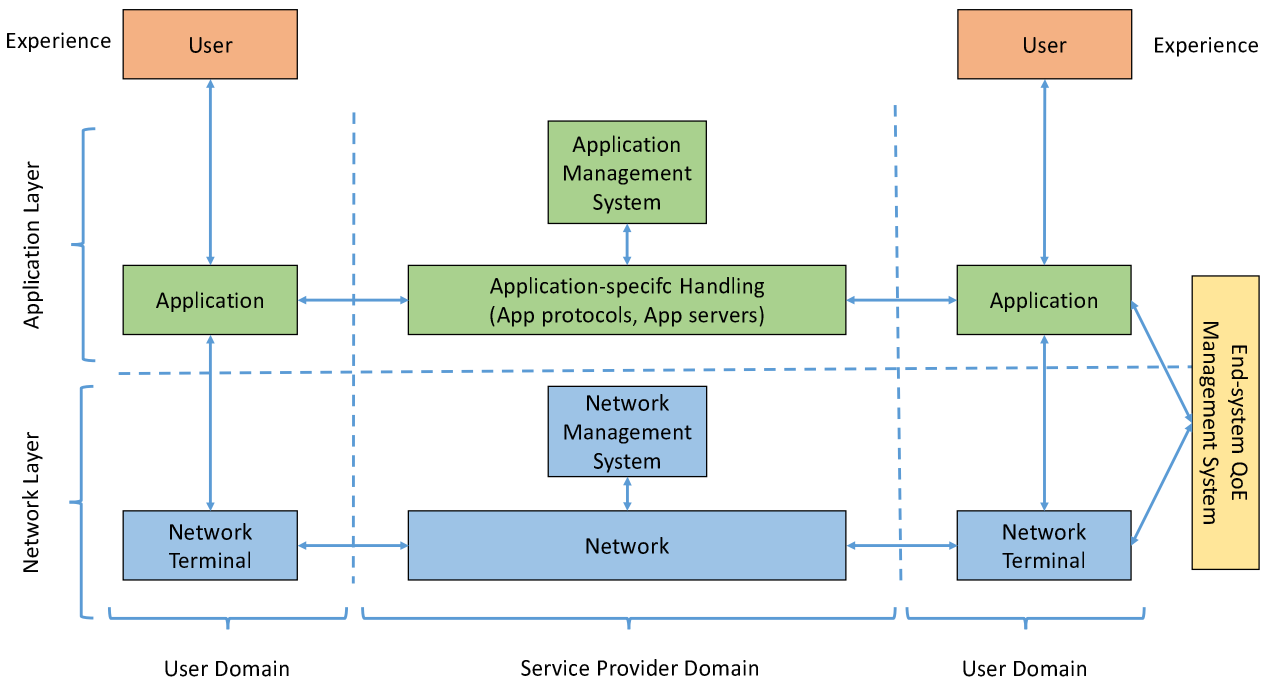

Figure 7-1: Simplified QoS Measurement Situations

7.2.2 Measurements with simulated traffic

The method described here, is to measure end-to-end quality metrics via simulated traffic and use the metrics as indicators for QoE. The measurement can be done on application level or on network level. The method shall use at least two measurement points and run simulated traffic between the points. The selection of simulated traffic tools and the location of the measurements points in the network need to be determined.

On the application level, application oriented key quality indicators as defined in clause 5 are measured. For cloud-based applications, the measurement can be done from an end-system to several instances of the cloud application.

On the network level, end-to-end measurements of key quality indicators as described in clause 6 are measured.

Two stakeholders have an interest in the results of this approach. First the end-user is interested in order to check service quality. The measured data is assessed and presented to the end-user for his information. Second, a service provider (network or application) is interested in order to test his own network or application with regards to QoE. In this case, the measurement results are assessed and actions are derived by the network or application management system of the service provider.

7.2.3 Measurements of real traffic

On the end-system, monitoring components measure the real traffic on the networking as well as the application level. The monitored data is collected and analysed either locally or via a remote management system. The key quality indicators are those defined in clause 5 and clause 6.

Because of the wide variety of end-user equipment and a variety of usage scenarios, the particular monitoring specifications are for further study.

7.3 Network slicing to improve QoE

7.3.1 Introduction

Network slicing and traffic steering are two major concepts of the F5G network architecture [1]. In the following clauses, the aspects of how QoE can be improved through network slicing are described.

7.3.2 F5G Underlay Network Planning

Traditionally, network planning is based on planning physical network capacity. The F5G architecture allows for dynamic changing of the underlay capacity for slice instances. Therefore, the network can be more dynamically planned and additional capacity can be provided to a network slice through re-configuration, assuming the physical resource is not exhausted.

The impact from changes in the service-oriented slice instance may need changes in the underlay network such that the QoE of services are still met.

7.3.3 F5G service-oriented slice modelling

For the case, where a network slice instance is used for a single service, the service is more easily modelled and simulated. Based on modelling and simulations, the required characteristics of the network slice instance is derived and configured in the real network. For the case, where a network slice instance is used for several services of similar characteristics, modelling and simulation is achieved.

The isolation capability of slicing ensures to stay within the per-slice boundaries and no interference from other applications and services can occur. This makes the service modelling and slice characteristics modelling much easier and more adaptive to changes in the service over time.

The service traffic modelling is service-dependent and is for further study.

7.3.4 Measuring the Quality of a Network Slice

Since a network slice includes virtual resources, many of the measurement mechanisms described in clause 7 are applicable. The QoS measurements and QoE assessment shall be performed on a per-slice basis, and therefore the measurement tools and interfaces shall support per-slice measurements.

In addition, the tenant of a network slice instance may want to perform QoS measurements to check whether the agreed SLA with the network slice provider is achieved. The tenant shall monitor the slice characteristics to guarantee QoS. F5G network shall be configured correctly to identify and map simulated traffic.

7.4 AI-based QoE Assessment

7.4.1 Based on Network QoS parameters

With the rapid development of broadband service, the demand for guaranteed Quality of Experience (QoE) is greater than the demand for bandwidth. QoE assessment reflects user experience, which is measured in the range from "very good" to "very bad" based on Key Quality Indicators (KQI). How to choose objective KQI to fully evaluate subjective QoE is challenging. This AI-based approach analyses and assesses the collected KQIs.

Operation and maintenance, such as service experience management, of the edge network elements are improved through the use of AI. AI modules deployed on edge network elements identify the different services. KQIs are collected from service data flows, and the AI algorithm analyses the data to assess the QoE.

AI-based service experience management allows for early indications of service quality degradation and indicates the need for network maintenance to satisfy the customers' requirements.

The AI-based QoE assessment for IP networks is shown in Figure 7-2.

Collected IP networks KQI data for the AI platform include:

1) The IP packet 5-tuples.

2) Network performance data: latency, bandwidth, jitter, packet loss, etc.

Active data is read (pull-mode) or received (push-mode) from network elements, gateway or user terminals.

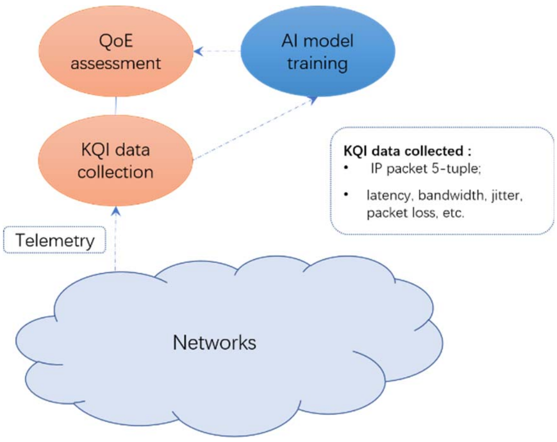

Figure 7-2: QoE assessment for IP networks

For PON network, the AI based QoE assessment is shown in Figure 7-3.

Collected PON KQI data for the AI platform includes:

1) OMCI data including ONU statistics; (as defined by [12]).

2) OLT statistics.

The collection of KQI data is either based on telemetry or on traditional polling approaches.

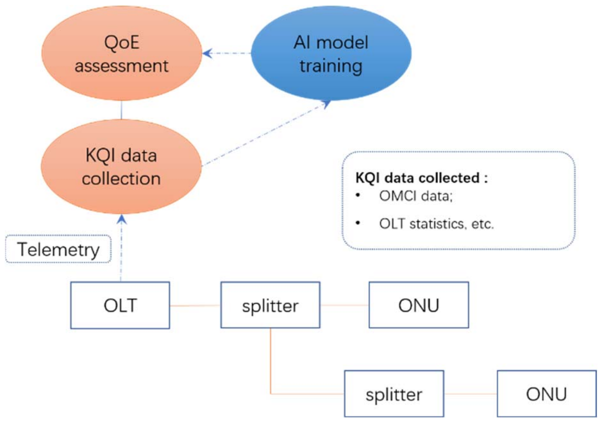

Figure 7-3: QoE assessment in a PON deployment

AI analysis is continuously applied to the collected data and provides the QoE estimations.

AI models are mainly trained offline, which has higher accuracy compared with online training. Offline training uses several data sources and over a longer period of time to achieve a more accurate model. The selection of training data from the database is more controllable. Additionally, the offline training runs a much higher number of iterations. Since services are continuously changing, the model shall be trained regularly in order to update and improve the models.

Online training is unsupervised and vulnerable to incorrect available data, even if it is adapting quickly to current network status.

Using the trained AI component and the collected KQI data, QoE assessment is performed. The QoE assessment is used for various actions. The actions to be taken are out of scope for the present document.

The benefit of this approach is that the service quality is monitored in real-time. Based on this, network degradation is detected, predicting network failure and enabling to prevent service outage.

7.4.2 Based on detected user behaviour

This approach is not measuring details of the traffic or performance indicators, but assesses the QoE from detectable user behaviour. For example, if a user performs a speed test frequently, it might indicate a problem with the bandwidth received. Another example is that the user frequently presses the re-load button on web or TV applications.

The assumption of this approach is that application specific user behaviour is detected in the application or in the network. This approach may need AI-based algorithms to learn the behaviour based on the data received.

7.5 Service Provider Domain oriented QoS Measurements and QoE Assessment

7.5.1 Introduction

The following approaches are measuring a set of key performance indicators in the service provider domain on application or network layer or both. The measurement can be done in different segments of the end-to-end network. The measured data is collected by traditional pull-mode monitoring or by push-mode telemetry approaches. The QoE is assessed based on measured performance indicators by different types of algorithms including analytics and artificial intelligence.

The benefit of this approach is that it is measuring real user communication sessions. The measured data depends on the location of the measurement, and sometime it is difficult to derive the user-specific QoE from that data, in general allowing for more general assessments of the perceived QoE.

7.5.2 Media application-based QoS Measurements and QoE Assessment

7.5.2.1 General Description

Clause 7.5.2 covers media services (e.g. video services) that are transported over UDP/RTP or TCP. For example, live TV services are normally carried over UDP/RTP in multicast mode, while Video on Demand (VoD) services are normally carried over TCP. Alternative protocols are possible, but are not covered in the present document and are for further study.

By observing and analysing the UDP/RTP or TCP segment headers, the UDP/RTP or TCP segment statistics (e.g. packet/segment loss, packet/segment transmission latency) are collected. This is a factor for evaluating transport quality of media services.

Furthermore, when the QoE of the media services deteriorates, error demarcation can be done based on the packet statistic observed at different measurement points.

7.5.2.2 Quality Measurement Methods for Media Services over UDP/RTP

1) Typical protocol stack and UDP/RTP packet headers of live video service over UDP/RTP

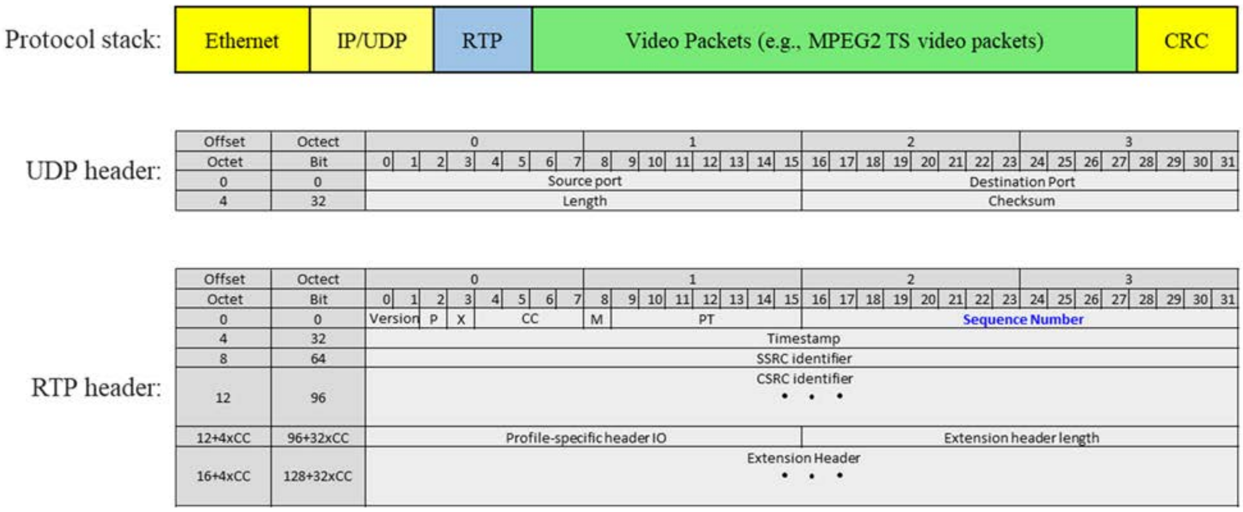

Figure 7-4: The protocol stack and the format of UDP/RTP header (IETF RFC 768 [8] and IETF RFC 3550 [9])

According to IETF RFC 3550 [9], the Sequence Number in the RTP header increments by one for each RTP data packet sent. By analysing the Sequence Numbers in the received UDP/RTP packet header, the packet loss statistics of the stream is collected and analysed.

2) UDP/RTP performance calculation principles

The following indicators in Table 7-1 are defined for the performance of the media services over UDP/RTP.

Table 7-1: Performance indicators for media services over UDP/RTP

Indicator	Indicator Description	Calculation
RTP-LR (RTP Loss Rate)	RTP packet loss rate within a measurement period.	**RTP-LR = Number of RTP lost packets / (Number of received RTP packets + Number of RTP lost packets)** Note that out-of-order packets are also treated as lost packets.
RTP-SE (RTP Sequence Error)	RTP out-of-order rate within a measurement period.	**RTP-SE = Number of RTP out-of-order packets / (Number of received RTP packets + Number of RTP lost packets)** Note that a received packet is treated as an out-of-order packet if its RTP Sequence Number is smaller than or equal to the current maximum RTP Sequence Number.
RTP-ELF (RTP Effective Loss Factor for FEC)	The rate at which the FEC scheme for the UDP/RTP fails to correct for errored packets within a measurement period.	This indicator is applicable only when a FEC scheme is used across UDP/RTP packets. Assume that a FEC scheme encodes each source data block into 'L' UDP/RTP packets, 'R' UDP/RTP packets of which are corrected packets. I.e. the source data block can be protected from 'R' UDP/RTP packet errors. In each sliding window with 'L' UDP/RTP packets, if the number of errored UDP/RTP packet is less or equal to 'R', then all the errored packets in this sliding window can be recovered by the FEC scheme effectively. Otherwise the FEC scheme fails to recover the errored packets. For a consecutive 'W' sliding windows, assume that there are 'F' sliding windows where the errored packets fail to be corrected, then: **RTP-ELF = F / W**
RTP-LP (RTP Loss Period)	Maximum number of consecutive RTP lost packets in a measurement period.	**RTP-LP = Maximum number of consecutive RTP lost packets.**

NOTE: The measurement period is a configurable time period.

For an example of this measurement method refer to Annex A.

7.5.2.3 Quality Measurement Methods for Media Services over TCP

1) TCP header format and TCP segment exchange

As defined in IETF RFC 793 [10], the TCP header includes the Sequence Number and the Acknowledgement Number, see Figure 7-5. During the TCP data transmission, the Sequence Number increases by the length of the TCP segment. In the example in Figure 7-6, a TCP segment with Sequence Number = 1 000 and segment length = 512 bytes is sent from the Sender to the Receiver. Then in the ACK message to this TCP segment, the Acknowledgement Number = 1 000 + 512 = 1 512. And in the next consecutive TCP segment sent by the Sender, the Sequence Number should be 1 512. If this is not the case then it implies that there was a TCP segment loss or a TCP segment retransmission.

NOTE: In most cases a TCP segment is carried by one IP packet, however there are some cases where this is not the case, e.g. when fragmented, so in the following description, the term TCP segment is used as in IETF RFC 793 [10].

Offset	Octect	0								1								2								3							
Octet	Bit	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
0	0	Source port																Destination Port															
4	32	Sequence Number																															
8	64	Acknowledgement number (if ACK set)																															
12	96	Data Offset				Reserved 000			NS	CWR	ECE	URG	ACK	PSH	RST	SYN	FIN	Window Size															
16	128	Checksum																Urgent pointer (if URG set)															
20	160	Options (if data ofset > 5. Padded at the end with "0" bytes if necessary)																															
• • •	• • •																																
60	480																																

Figure 7-5: TCP header format (IETF RFC 793 [10])

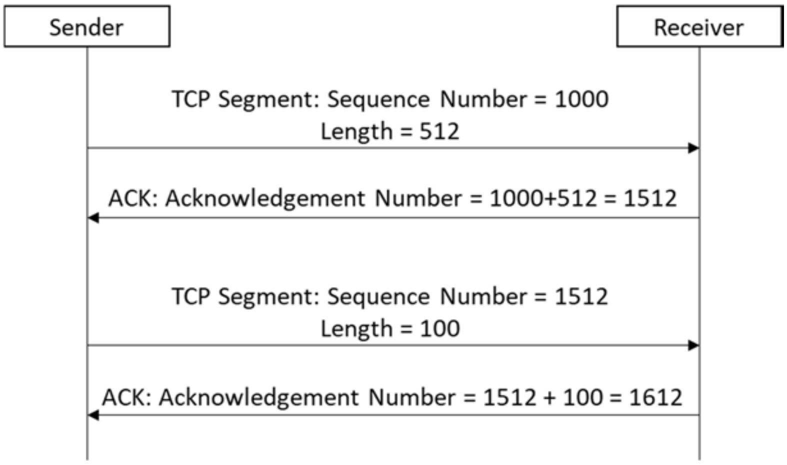

Figure 7-6: Example TCP segment exchange

2) Overview of quality measurement method for TCP

Figure 7-7 shows the overview of TCP quality measurement.

By detecting non-consecutive TCP Sequence Numbers in a TCP flow at a measurement point in the network, the number of upstream lost TCP segments are inferred, and the TCP Segment loss rate on the upstream of the measurement point (USLR, Upstream Segment Loss Rate) are calculated.

By counting the retransmitted TCP segments, the total number of lost TCP segments are measured, and therefore the number of downstream lost TCP segments are inferred, and then the TCP segment loss rate on the downstream of the measurement point (DSLR, Downstream Segment Loss Rate) is calculated.

The round-trip transmission time on the downstream of the measurement point (DRTT, Downstream Round-Trip Time) is evaluated by the timestamps of the downlink data TCP segments and the corresponding uplink ACK segment.

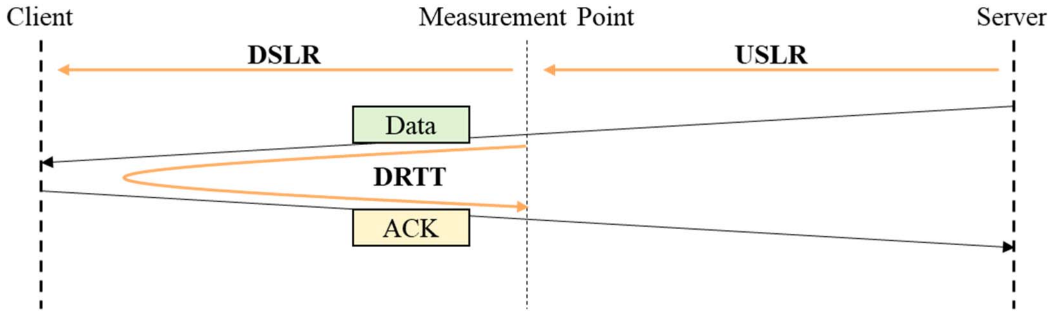

Figure 7-7: TCP quality measurement

3) TCP performance calculation principles

The following indicators in Table 7-2 are defined for the performance of the media services over TCP.

Table 7-2: TCP performance indicators

Indicator	Indicator Description	Calculation
MFR (Mean Flow Rate)	Average rate within a measurement period.	**MFR = Total length of received TCP segments / measurement period.**
USLR (Upstream Segment Loss Rate)	TCP Segment loss rate on the upstream of the measurement point within a measurement period.	Non-consecutive TCP Sequence Numbers are considered as upstream segment loss. Within a measurement period: **UPLR = Number of upstream lost TCP segments / Total number of TCP segments.** Where: Number of upstream lost TCP segments = (current TCP Sequence Number - previous TCP Sequence Number) / Average TCP segment length - 1 Note that the number of upstream lost TCP segments is calculated approximately because of the average TCP segment length. This is still reasonable because video streams are normally divided into multiple segments with the same size equal to MTU.
DSLR (Downstream Segment Loss Rate)	TCP Segment loss rate on the downstream of the measurement point within a measurement period.	Within a measurement period: **DSLR = Number of downstream lost TCP segments / Total number of TCP segments.** Where: Number of downstream lost TCP segments = Total number of lost TCP segments - Number of upstream lost TCP segments, and: Total number of lost TCP segments = the number of retransmitted TCP segments Note that a received TCP segment is treated as a lost TCP segment when its TCP Sequence Number is smaller or equal to the current maximum TCP Sequence Number (i.e. this segment is a retransmitted TCP segment because of TCP segment loss).
DRTT (Downstream Round-Trip Time)	Average round-trip transmission time on the downstream of the measurement point within a measurement period.	Within a measurement period: For each pair of (TCP segment, ACK segment): **DRTT = average value of (timestamp of ACK segment - timestamp of TCP segment).**

For an example for this measurement method refer to Annex B.

8 Summary of Requirements and Recommendations of F5G QoE

8.1 Requirements

In the following clause the requirements of F5G QoE are presented. For detailed description of these requirement descriptions refer to the previous clauses.

[Req-1] The F5G network shall support telemetry.

[Req-2] The F5G network shall support the capability of telemetry to frequently send measured data.

[Req-3] The F5G network shall support the capability of telemetry to export fine grained statistics.

[Req-4] The F5G network telemetry interface shall support per-slice QoS measurement data.

[Req-5] The F5G network shall support end-to-end QoE assessment in the CPN, Access Network, Aggregation Network, and Core Network.

[Req-6] The F5G network shall support AI-based QoE assessment based on measured network or application performance data.

[Req-7] The F5G CPN shall provide a mechanism to improve QoE in the customer premises network (residential, enterprise, verticals).

[Req-8] The F5G service and underlay plane shall support network-layer QoS measurement mechanisms to support QoE assessment and management.

[Req-9] The F5G service and underlay plane shall support application-layer QoS measurement mechanisms to support QoE assessment and management.

8.2 Recommendations

It is recommended that for Cloud VR applications, the methodology to measure the impacting factors are defined and standardized.

It is recommended to study dynamic slice dimensioning and adaptation based on application and service traffic modelling.

It is recommended to study different ways to derive user satisfaction based on the detection of user's behaviour.

It is recommended to study the correlation between subjective experience of new applications and the F5G network performance measurement.

Annex A (informative): Example of quality monitoring for media services over UDP/RTP

Equipment with Ethernet frame forwarding capability act as the measurement points for the UDP/RTP performance measurement, including the ONUs, CPEs, OLTs, and OTN. The example in Figure A.1 uses the uplink port of OLT (maybe carried by IP/Ethernet or OTN Aggregation Network) as the non-intrusive performance measurement point.

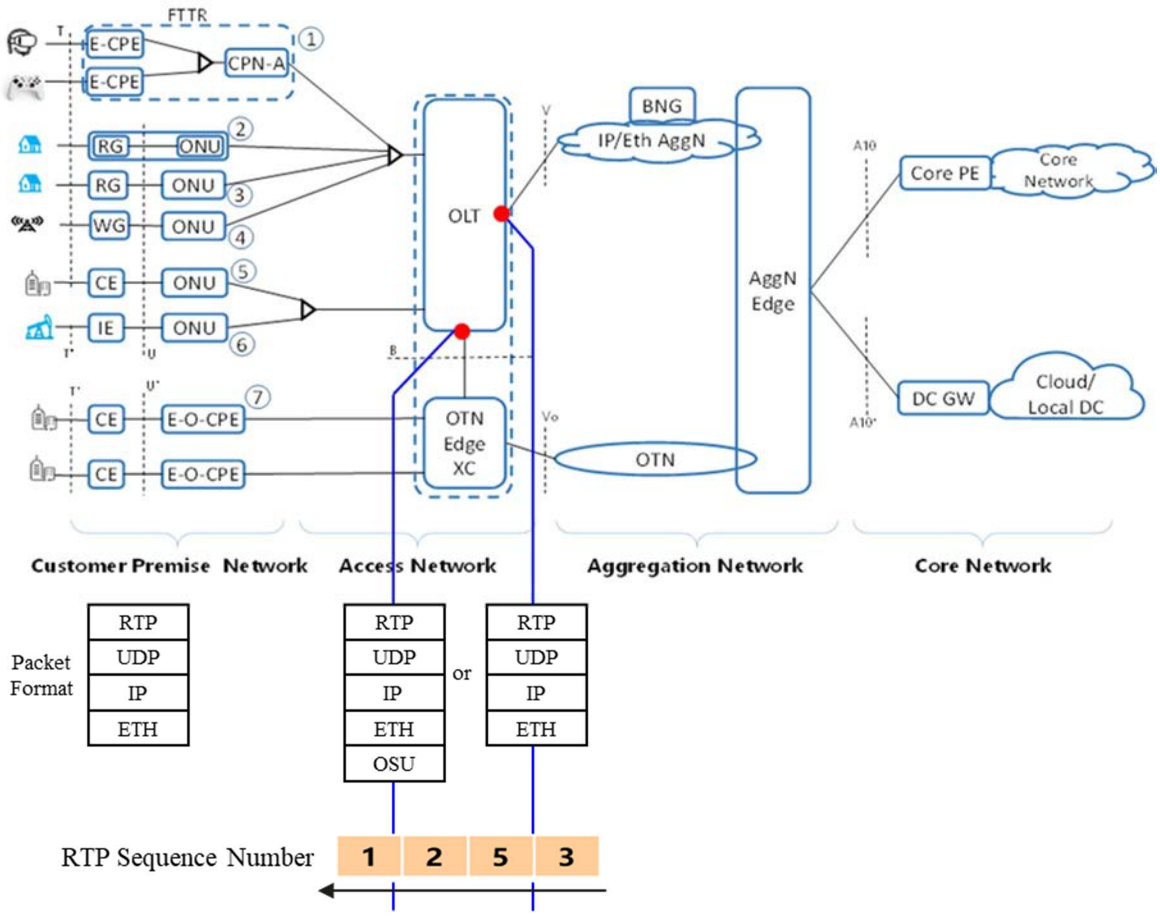

Figure A-1: Example of quality monitoring for media services over UDP/RTP

- Number of received RTP packets = 4
  - 4 packets, with the Sequence Number 1, 2, 5 and 3 are received.
- Number of RTP lost packets = 2
  - If (current Sequence Number – previous Sequence Number - 1 > 0), packet loss has occurred.
    - In this example the packet loss occurs between the two packet Sequence Numbers 5 and 2.
    - Number of RTP lost packets = 5 - 2 - 1 = 2 > 0.
- Number of RTP out-of-order packets = 1
  - If (current Sequence Number < previous Sequence Number), the current packet is an out-of-order packet.
    - In this example packet Sequence Number 3 is an out-of-order packet.
    - 3 < 5 therefore packet 3 is out of order.

- Maximum number of consecutive RTP lost packets = 2
  - Maximum number of consecutive RTP lost packets = max (current Sequence Number - previous Sequence Number - 1).
    - In this example the maximum consecutive RTP lost packets happens between the two packets with Sequence Number 3 and 5.
    - Maximum number of consecutive RTP lost packets = max (5 - 2 - 1) = 2.

Annex B (informative): Example of quality monitoring for media services over TCP

Equipment with Ethernet frame forwarding capability is used as the measurement points to test performance indicators, including ONUs, CPEs, OLTs, and OTNs. The example in Figure B.1 uses the uplink port of OLT (may be carried by IP/Ethernet or OTN Aggregation Network) as the non-intrusive performance measurement point.

Ethernet or OTN Aggregation Network) as the measurement point.

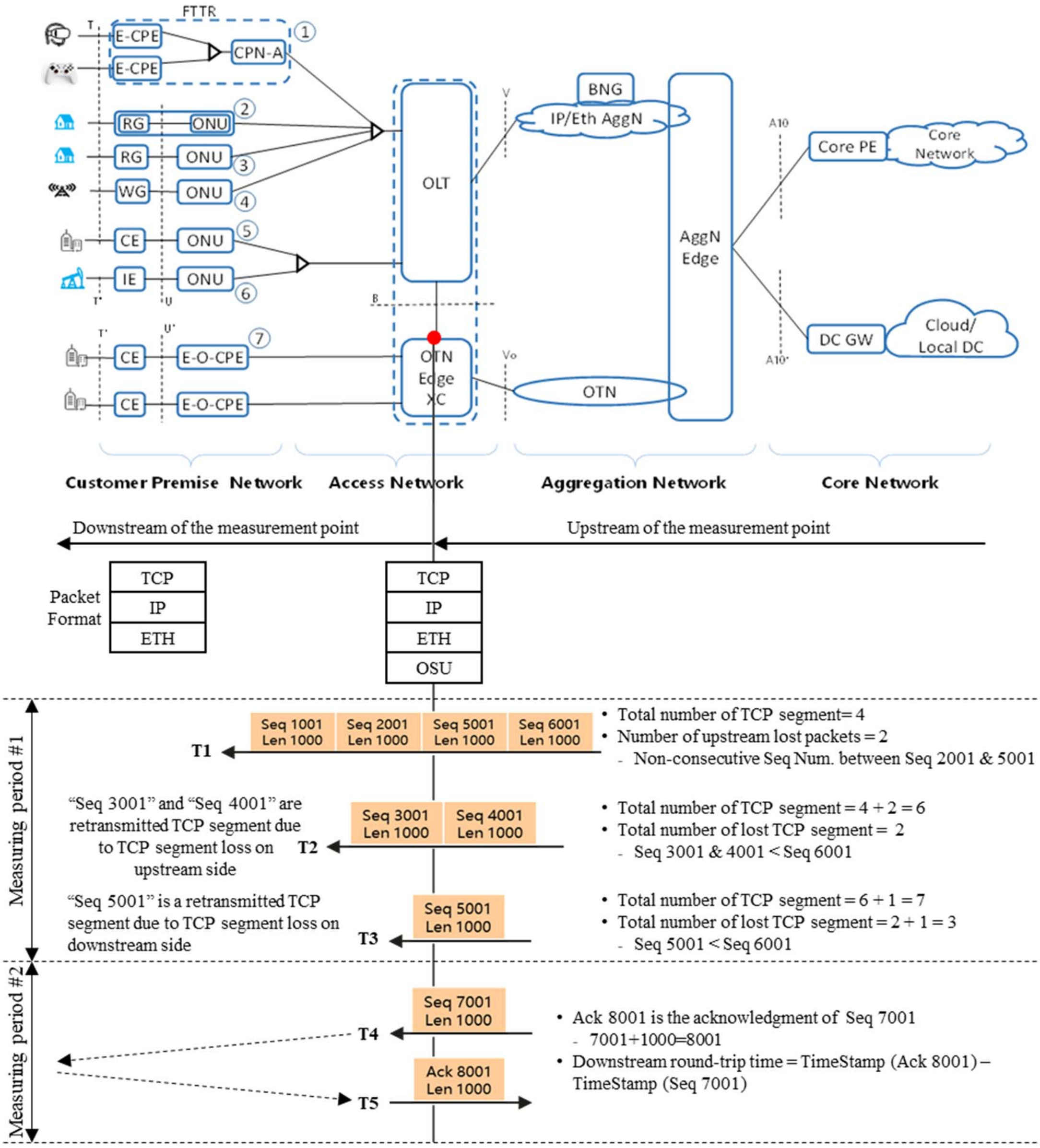

Figure B-1: Example of TCP Service Quality Monitoring

- Assume that T1~T3 is a measurement period, then during T1~T3:
  - Total number of TCP segments = 4 + 2 + 1 = 7
  - Number of upstream lost TCP segments = 2
  - Total number of lost TCP segments = 2 + 1 = 3
  - Number of downstream lost TCP segments = 3 - 2 = 1

- Assume that T4~T5 is another measurement period, then during T4~T5:
    - The round-trip transmission time on the downstream of the measurement point = timestamp of ACK segment - timestamp of TCP segment = T5 - T4

History

Document history		
V1.1.1	March 2022	Publication