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SERIES J: CABLE NETWORKS AND TRANSMISSION OF TELEVISION, SOUND PROGRAMME AND OTHER MULTIMEDIA SIGNALS

Artificial intelligence (AI) assisted cable networks – Data models of the communicated data for the AI-assisted cable network platform

Functional requirements of E2E network platforms to enhance the delivery of cloud-VR services over integrated broadband cable networks

Recommendation ITU-T J.1631

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Summary

Recommendation ITU-T J.1631 describes functional requirements of the end-to-end (E2E) network platform to deliver 360°/Virtual Reality (VR) video services from the video cloud to terminal devices over integrated broadband cable networks. Cloud VR is a new cloud computing technology for VR services. With fast and stable transport networks, VR contents are stored and rendered in the cloud. Audiovisual contents are encoded, compressed and transmitted to user terminals. This Recommendation specifies the network requirements of Cloud VR services.

NOTE – Integrated broadband cable networks can be referred to as a cable network, e.g., coaxial cable, optical fibre, hybrid fibre coaxial (HFC), etc., that also has capability to provide broadband services integrated with television services over the same network.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T J.1631	2021-11-24	9	11.1002/1000/14648

Keywords

Cloud-VR, network bandwidth, network delay jitter, network latency, network packet loss, requirements.

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* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Introduction

This Recommendation is Part 1 of a multipart deliverable covering the functional requirements of the end-to-end (E2E) network platform to deliver 360°/Virtual Reality (VR) video services from the video cloud to terminal devices over integrated broadband cable networks, as identified below:

Part 1: Functional Requirements

Part 2: High level system architecture

Recommendation ITU-T J.1631

Functional requirements of E2E network platform to enhance the delivery of cloud-VR services over integrated broadband cable networks

1 Scope

This Recommendation describes functional requirements of the end-to-end (E2E) network platform to deliver 360°/Virtual Reality (VR) video services from the video cloud to terminal devices over integrated broadband cable networks. Cloud VR is a new cloud computing technology for VR services. With high-quality transport networks with high bandwidth and low latency, VR contents are stored and rendered in the cloud. Audiovisual contents are encoded, compressed and transmitted to user terminals. Local rendering requires expensive high-performance devices to provide immersive user experience.

The cloud VR services are divided into two categories based on the interaction characteristics. One category is weak-interaction VR services; and the other is strong-interaction VR services. Weak-interaction VR services mainly comprise VR video services, including IMAX theatre, 360° panoramic video and VR live broadcast. Strong-interaction VR services include VR games, VR home fitness and VR social networking.

The evolution of cloud VR service experience is divided into the following four phases: fair experience phase (FEP), comfortable experience phase (CEP), ideal experience phase (IEP) and ultimate experience phase (UEP). In these four phases, the typical content is 4K, 8K, 12K and 24K, respectively. The terminal screen resolution is typically 2K, 4K, 8K and 16K, respectively. The quality of image viewed by users is equivalent to the pixels per degree (PPD) effect of 240P/380P, 480P, 1080P and 4K on a traditional TV, respectively.

To ensure good experience for the cloud VR services, network performance indicators, e.g., bandwidth, latency, delay jitter and packet loss rate, are suggested as performance requirements (informative).

NOTE 1 – Integrated broadband cable networks can be referred to as a cable network, e.g., coaxial cable, optical fibre, hybrid fibre coaxial (HFC), that also has capability to provide broadband services integrated with television services over the same network.

NOTE 2 – Network performance indicators can be referred to as network/transmission related factors which are defined in [b-ITU-T G.1035] for VR services.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

None.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 immersion [b-ITU-T G.1035]: A psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences.

3.1.2 motion-to-photon latency [b-ITU-T G.1035]: The time it takes between the user moving their head and this motion being reflected on the screen of the head-mounted display (HMD).

3.1.3 virtual reality [b-ITU-R BT.2420-0]: A technology that replicates an environment, real or imagined, and simulates a user's physical presence and environment to allow for user interaction. Virtual reality artificially creates a sensory experience, which in principle can include sight, touch, hearing, and smell. The current VR devices primarily present content to the visual and auditory systems. On occasion, haptics information is also included.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 asynchronous rendering: The rendering on the VR terminal attempts to catch up with the actual rendering on the server or host PC.

3.2.2 full-view transmission: Involves sending 360° images to terminals. When users turn their heads and images they see are switched according to their Field of View (FOV), and terminals perform just-in-time processing on images, such as bit stream parsing, video decoding and image rendering.

3.2.3 field of view transmission: Focuses on the high-quality transmission of images within the current FOV.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3I	Immersion, Interaction and Imagination
AR	Augmented Reality
CDN	Content Delivery Network
CEP	Comfortable Experience Phase
CMTS	Cable Modem Termination System
DBA	Dynamic Bandwidth Assignment
DCN	Data Centre Network
E2E	End-to-end
FEP	Fair-experience Phase
FOV	Field of View
GOP	Group of Pictures
HFC	Hybrid Fibre Coaxial
IEP	Ideal-experience Phase
IMAX	Image Maximum

MTP	Motion-to-Photon Latency
OLT	Optical Line Terminal
ONT	Optical Network Termination
PON	Passive Optical Network
PPD	Pixels Per Degree
QoS	Quality of service
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UEP	Ultimate-experience Phase
VR	Virtual Reality
WDM	Wavelength Division Multiplexing

5 Overview of cloud-VR Services

This Recommendation describes functional requirements of the E2E network platform to deliver 360°/VR video services from the video cloud to final customers over an integrated broadband cable network. Cloud VR is a new cloud computing technology for VR services. With fast and stable transport networks, VR contents are stored and rendered in the cloud. Audiovisual contents are encoded, compressed and transmitted to user terminals. Local rendering requires expensive high-performance devices to provide acceptable user experience. With Cloud VR, users enjoy VR services without purchasing expensive hosts or high-end computers. This is then likely to lead to wide popularity.

VR is a virtual environment constructed by computers, wherein people can interact in real-time using three-dimensional (3D) spatial information. According to the VR and augmented reality (AR) industry report [b-VR/AR], it is predicted that the following VR applications will gain popularity first: VR image maximum (IMAX), VR 360° video, VR live broadcast, VR gaming and VR education. Cloud VR services in these application scenarios are further classified as strong- or weak-interaction services.

Weak-interaction VR services mainly comprise VR video services, including IMAX theatre, 360° panoramic video and VR live broadcast. Users can select the view and location, but cannot interact with (e.g. touch) entities in a virtual environment. Strong-interaction VR services include VR games, VR home fitness and VR social networking. In these scenarios, users can interact with a virtual environment through interactive devices with real-time responses.

6 Four phases of cloud-VR Development

The development of Cloud VR focuses on continuous improvement in image quality, interaction and immersive experience. The synergy between content production, transmission and network technologies determines the level of Cloud VR experiences. This Recommendation divides the evolution of Cloud VR service experience into the following four phases: FEP, CEP, IEP and UEP.

FEP [b-VR-Network]: In this phase, typical content is 4K, and the terminal screen resolution is 2K. The quality of the image viewed by users is equivalent to the PPD effect of 240P/380P on a traditional TV. For Cloud VR video services, the main solution is full-view transmission mode. To ensure good experience, the frame rate of strong-interaction VR services is higher than that of common VR video services. On the other hand, FOV transmission mode instead of full-view transmission mode is normally used for strong-interaction VR (e.g., VR games) in this phase. Terminals support asynchronous rendering to provide a smooth experience.

CEP [b-VR-Network]: In this phase, typical content is 8K, and the terminal screen resolution is 4K. The quality of image viewed by users is equivalent to 480P video on traditional TV. In this phase, network bandwidth and latency must be significantly improved to ensure good experience. For Cloud VR video services, full-view transmission will be the first choice to ensure good viewing and interaction experience. However, 360° 8K 3D video requires a bandwidth of higher than 100 Mbit/s for full-view transmission. The FOV transmission solution can reduce the bandwidth requirements, especially for strong-interaction VR services, which are in higher resolution and require bandwidth.

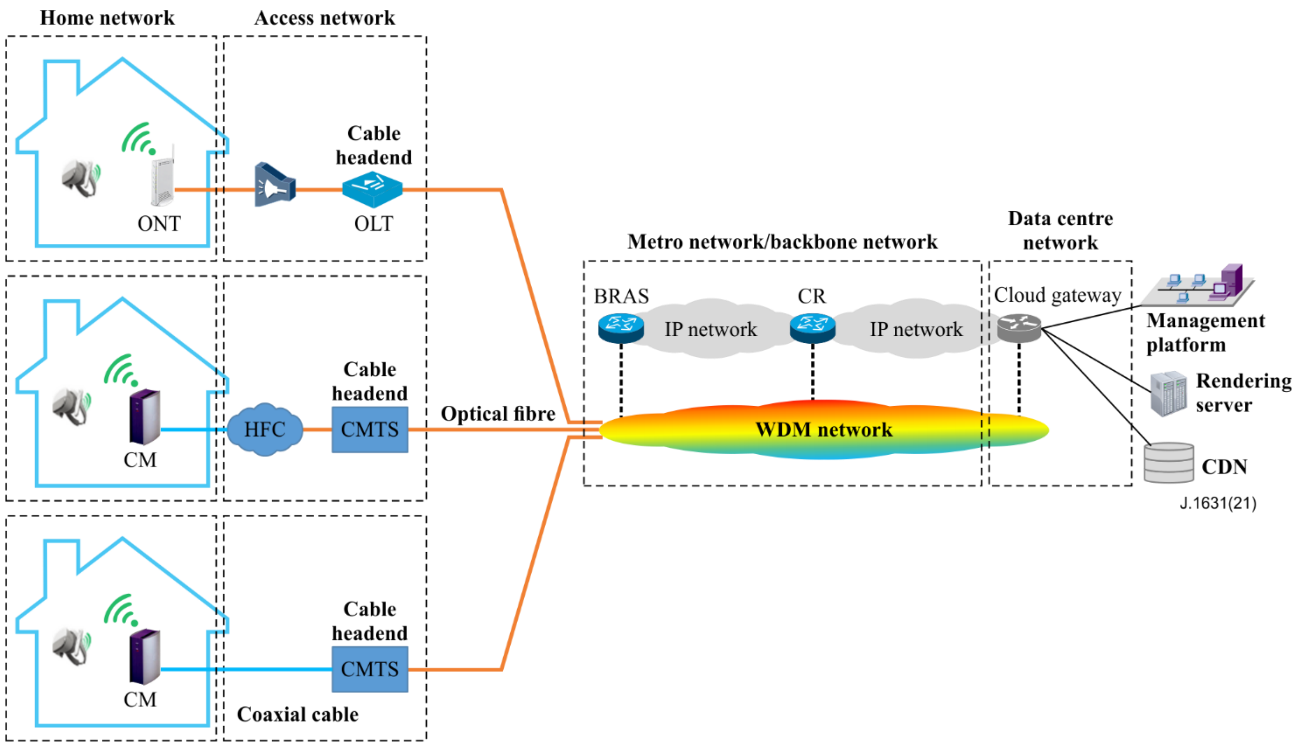
IEP [b-VR-Network]: In this phase, typical content is 12K, and the terminal screen resolution is 8K. Chip performance and ergonomics are improved. The quality of image viewed by users is equivalent to 1080P video on traditional TV. For Cloud VR video services, the full-view transmission solution requires higher network bandwidth, while the FOV solution has lower requirements. Hence, FOV will be the mainstream solution. In the case of strong-interaction Cloud VR services, the resolution is significantly improved, further increasing the bandwidth requirements. In addition, to ensure good interaction experience, lower network latency is required.

UEP: In this phase, typical content is 24K, and the terminal screen resolution is 16K. The quality of image viewed by users is equivalent to 4K video on traditional TV. For both Cloud VR video and strong-interaction Cloud VR services, FOV will be the mainstream solution. The bandwidth and latency requirements are improved. In this phase, the VR contents are completely immersed, without distinction between reality and virtual reality.

7 Network requirements of cloud-VR

7.1 Reference architecture

The reference network architecture for bearing Cloud VR services is shown in Figure 1. There are four nodes: home network node, access network node, metro network/backbone network node and data centre network (DCN) node.



Legend: ONT – optical network terminal; OLT – optical line terminal; CM – cable modem; HFC – hybrid fibre-coaxial; CMTS – cable modem termination system; BRAS – broadband remote access server; CR – core router; CDN – content delivery network.

Figure 1 – Cloud VR reference network architecture

NOTE – Integrated broadband cable networks can be referred to as a cable network, e.g., coaxial cable, optical fibre, HFC, etc., that has also capability to provide broadband services integrated with television services over the same network.

7.2 Service requirements

To enhance the delivery of Cloud VR services, the integrated broadband cable network shall have the following requirements in terms of network, quality of service (QoS), service provision and network management.

Network: This service requires the network to provide bandwidth sufficient to transfer data between Cloud VR terminals and servers to accomplish real-time communication.

QoS: This service requires the consideration of the QoS aspect of Cloud VR to provide a good user experience of the services.

Service provision: This service's requirements include content delivery service provision requirements for the implementation of the content delivery network (CDN).

Network management: When Cloud VR services are deployed, these services may need to be managed remotely.

7.3 Functional requirements

Network requirements: Each node of the reference network architecture should have the following requirements.

The home network provides WiFi access and network dial-up authentication services for cloud VR terminals. It should at least consist of optical network termination (ONT) or cable modem, and optionally include home routers. Service-specific parameters and functionalities are needed in the home network to improve efficiency. Service-specific parameters and functionalities (e.g., WiFi scheduling and data distribution) are needed in the home network to improve network performance.

The access network provides the fibre infrastructure for each home, and aggregates, processes, and distributes the data of multiple home networks through the optical line terminal (OLT) or cable modem termination system (CMTS). Enhanced dynamic bandwidth assignment (DBA) is required to decrease the latency of the Cloud VR.

In the IP part of the metro network/backbone network, the broadband remote access server (BRAS) works as the gateway to provide IP addresses for the ONT and sends the data packets to the correct destination according to the IP addresses. The metro network may have multiple external networks, and core routers are responsible for aggregation and traffic distribution. The wavelength division multiplexing (WDM) network serves as a base infrastructure to provide high-speed transmission capabilities for upper-layer networks and even to provide one-hop OLT-based private line services to the cloud servers.

DCN is interconnected to the rendering server/CDN server. It is also connected to the metro/backbone network through the cloud gateway node. The CDN is required to support the provision of services, e.g., various multivendor services, content downloading and delivery of multiple audiovisual streams. DCN is outside the scope of this Recommendation.

QoS requirements: To assure the E2E service experience, priority (or class) based QoS technique that are being used in an IP network should be considered. With the priority QoS technique, intermediate routing entities between the source and the destination of a Cloud VR stream determine how to handle an IP packet from the Cloud VR stream according to the priority field in the header of that IP packet. The priority field has been set to a certain value (this is called QoS marking or classification) by the source. With this technique, higher priority IP packets will get better treatment during transit of each node to reach the destination, thus their stream can achieve better QoS than others that have a lower priority [b-ITU-T H.622.1].

NOTE – [b-ITU-T H.622.1] describes the QoS requirements for IPTV services. For Cloud VR, this QoS requirements are also can be considered.

Network management requirements: It is very important for service or network providers to have a standardized way to remotely manage Cloud VR services efficiently and economically. QoS management is a critical network management aspect for ensuring the correct delivery of the services. System-level fault (e.g., hardware, operating system or software related) can optionally be detected and communicated to the service or network provider.

7.4 Performance requirements

Performance requirements in this clause are informative.

7.4.1 Key factors affecting cloud VR experience

The three characteristics and advantages of VR are immersion, interaction and imagination (3I).

– Immersion [b-ITU-T G.1035]: 3D images are generated by computers to create a virtual environment that feels like the physical world.
– Interaction [b-ITU-T G.1035]: Users can use sensor devices to interact with each other in the virtual environments generated and feel like they are in the real world.
– Imagination: The virtual environments inspire the imagination of users.

The evaluation factors of VR experience include sense of reality, sense of interaction and sense of pleasure (Figure 2).

– Sense of reality: Sense of reality depends on resolution, colour depth, frame rate and encoding compression technologies. If the quality of the audiovisual content is too poor, the virtual environments do not feel real and users are unable to immerse themselves. The bandwidth of the Cloud VR bearer network shall meet the requirements of high-quality video transmission to ensure good user experience.

– Sense of interaction: The contents of cloud VR are computed and rendered on the cloud. The entire latency from remote processing compromises the sense of immersion and imagination. The dizziness caused by latency is the biggest problem that cloud VR is facing. In addition, the latency in loading, switchover and joystick operations compromises VR interaction experience.

– Sense of pleasure: Sense of pleasure depends on the smoothness of VR services. Frame freezing and artefacts compromise the pleasure experience. Therefore, network performance indicators, e.g., bandwidth, latency, delay jitter and packet loss rate, shall meet the network requirements of Cloud VR services.

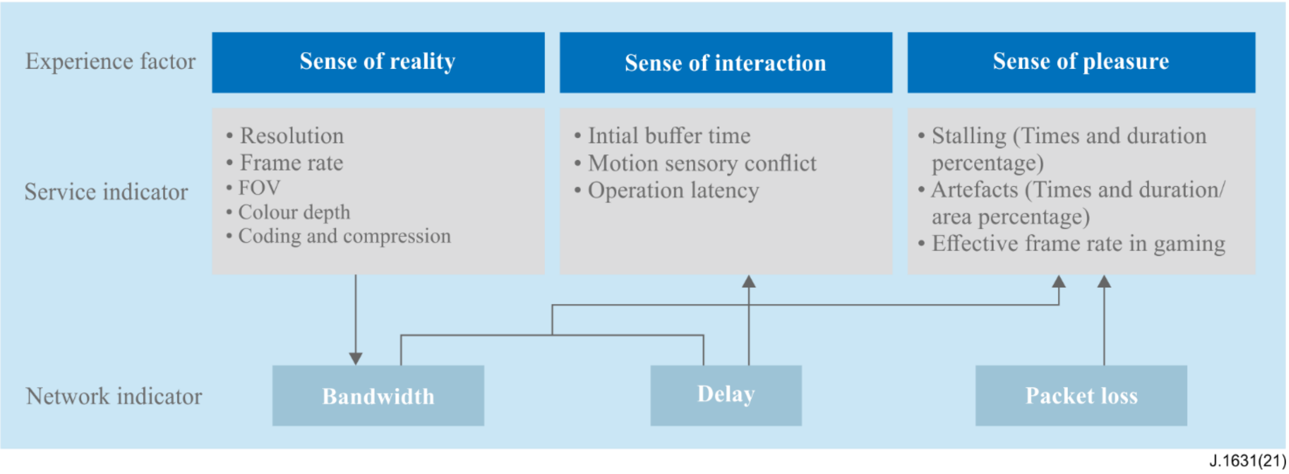


Figure 2 – Relationship between the key factors of cloud VR experience and the network

7.4.2 Network latency requirements of cloud VR

For traditional 4K services, network latency only slightly affects the channel switching time and loading duration. Therefore, the network latency requirements of traditional 4K services are not strict. The network latency requirements of the 4K can be lowered based on network conditions. However, the network latency of strong-interaction VR services is deterministic because the contents are remotely rendered in the cloud. Otherwise, the screen refreshing quality and user interaction would be compromised.

7.4.2.1 Latency requirements

Network latency between 20 ms to 40 ms can meet the requirements of cloud VR video services. Latency only affects the loading time. However, strong-interaction cloud VR services pose the following latency requirements to ensure good user interaction and pleasure experiences:

1) The motion-to-photon latency (MTP) latency is suggested to be less than or equal to 20 ms.

2) The requirements on cloud rendering and streaming latency are suggested to be 30 ms to 70 ms.

3) The acceptable operations latency is suggested to be less than or equal to 100 ms.

7.4.2.2 Network latency distribution in cloud VR

Latency in cloud rendering and streaming derives from three factors: processing on the cloud, transmission on the network and processing inside the terminal.

The suggested network latency levels for home WiFi, access network and metro network latency can be found in Appendix I.

Please refer to Appendix I, Table I.1, for more details and examples of E2E network RTT requirements of Cloud VR.

7.4.3 Network delay jitter requirements of cloud VR

Generally, delay jitter is related to the line quality and buffer size of the equipment. Firstly, delay jitter from home WiFi is for the largest part due to the air channel quality. Secondly, large-buffer routers increase delay jitter up to 20 ms. The buffer of the access network is small, and the delay jitter is within 5 ms.

The suggested network delay jitter requirements can be found in Appendix I. Please refer to Appendix I, Table I.2, for more details and examples of network delay jitter requirements of cloud VR.

7.4.4 Network bandwidth requirements of cloud VR

The immersive terminals of cloud VR have a greater FOV than traditional TVs. To achieve the same definition as 4K video, the resolution, frame rate and bitrate of cloud VR are higher than those of the 4K video services, posing higher bandwidth requirements on networks.

7.4.4.1 Factors affecting cloud VR bandwidth

The factors that affect the bandwidth requirements of Cloud VR include resolution, frame rate, colour depth, FOV, coding compression and transmission mode.

7.4.4.2 Network bandwidth requirements

For cloud VR video services, full-view transmission is used in the FEP. With the development of industry and the increase of video resolution, the FOV transmission solution can be used to minimize the bandwidth requirements of the networks.

For strong-interaction VR services, FOV mode is used, and real-time rendering is performed based on the current FOV. Strong-interaction service streams consist of I-frames and P-frames. An I-frame contains all the information about the image, and intraframe coding is used to restore the image. A P-frame is a forward predicted frame, and the image is restored algorithmically based on the previous I-frame or P-frame. Each group of pictures (GOP) contains one I-frame and N P-frames, where N = (GOP time) × (frame rate) −1.

The suggested per-user bandwidth requirements of strong-interaction and weak-interaction cloud VR services can be found in Appendix I. Please refer to Appendix I, Table I.3, for more details and examples of network bandwidth requirements of Cloud VR.

7.4.5 Network packet loss requirements of cloud VR

Currently, cloud VR services typically use transmission control protocol (TCP) as the transmission protocol. Packet loss reduces TCP throughput and causes frame freezing.

User datagram protocol (UDP), which is a connectionless protocol, is widely used for strong-interaction and live video services. There will be more packet loss compared to using TCP, potentially causing problems such as erratic display and black screen.

The suggested network packet loss rate requirements of strong-interaction and weak-interaction cloud VR services can be found in Appendix I. Please refer to Appendix I, Table I.4 and Table I.5, for more details and examples of network packet loss rate requirements of weak-interaction and strong-interaction cloud VR services, respectively.

Appendix I

Example of network requirements of cloud VR

(This appendix does not form an integral part of this Recommendation.)

This appendix contains informative material concerning the network requirements of cloud VR services.

I.1 Example of E2E network RTT requirements of cloud VR

Table I.1 describes the suggested network latency requirement values that need to be considered in each phase.

Table I.1 – Example of E2E network RTT requirements of cloud VR

Phase	Transmission distance	FEP	CEP	IEP	UEP
E2E network RTT	<600 km	<20 ms	<20 ms	<10 ms	<8 ms

NOTE 1 – Network latency requirements of cloud VR services in FEP are based on experimental results.

NOTE 2 – Network latency requirements of cloud VR services in CEP, IEP and UEP are suggested values.

I.2 Example of network delay jitter requirements of cloud VR

Table I.2 describes the suggested network delay jitter requirement that needs to be considered in each phase.

Table I.2 – Example of network delay jitter requirements of cloud VR

Phase	FEP	CEP	IEP	UEP
Total delay jitter	<15 ms	<15 ms	<10 ms	<7 ms

NOTE 1 – Network delay jitter requirements of Cloud VR services in FEP are based on experimental results.

NOTE 2 – Network delay jitter requirements of Cloud VR services in CEP, IEP and UEP are suggested values.

I.3 Example of network bandwidth requirements of cloud VR

Table I.3 describes the suggested per-user bandwidth requirements of strong-interaction and weak-interaction services that need to be considered in each phase.

Table I.3 – Example of network bandwidth requirements of cloud VR

Phase		FEP	CEP	IEP	UEP
Typical full-view resolution		4K	8K	12K	24K~
Typical terminal resolution		2–3K	4K	8K	16K~
Weak-interaction VR service	Bit rate	Full-view ≥ 40 Mbit/s	FOV ≥ 80 Mbit/s	FOV ≥ 280 Mbit/s	FOV ≥ 760 Mbit/s
	Bandwidth requirement	≥60 Mbit/s	≥120 Mbit/s	≥420 Mbit/s	≥1 140 Mbit/s

Table I.3 – Example of network bandwidth requirements of cloud VR

Phase		FEP	CEP	IEP	UEP
Strong-interaction VR service	Bit rate	≥40 Mbit/s	≥65 Mbit/s	≥270 Mbit/s	≥770 Mbit/s
	Bandwidth requirement	≥80 Mbit/s	≥130 Mbit/s	≥540 Mbit/s	≥1 540 Mbit/s

NOTE 1 – Network bandwidth requirements of cloud VR services in FEP are based on experimental results.

NOTE 2 – Network bandwidth requirements of cloud VR services in CEP, IEP and UEP are based on theoretical calculation.

I.4 Example of network packet loss requirements of cloud VR

Table I.4 describes the suggested network packet loss rate requirements of weak-interaction service that need to be considered in each phase.

Table I.4 – Example of network packet loss requirements of weak-interaction cloud VR services

Phase	FEP	CEP	IEP	UEP
RTT	30 ms	20 ms	10 ms	10 ms
Bandwidth	60 Mbit/s	120 Mbit/s	420 Mbit/s	1 140 Mbit/s
Packet loss rate	$\leq 10^{-4}$	$\leq 10^{-5}$	$\leq 10^{-6}$	$\leq 10^{-6}$

NOTE 1 – Network packet loss rate requirements of weak-interaction cloud VR services in FEP are based on experimental results.

NOTE 2 – Network packet loss rate requirements of weak-interaction cloud VR services in CEP, IEP and UEP are based on theoretical calculation.

Table I.5 describes the suggested network packet loss rate requirements of strong-interaction service that need to be considered in each phase.

Table I.5 – Example of network packet loss requirements of strong-interaction cloud VR

Phase	FEP	CEP	IEP	UEP
RTT	20 ms	20 ms	10 ms	8 ms
Bandwidth	80 Mbit/s	130 Mbit/s	540 Mbit/s	1 540 Mbit/s
Packet loss rate	$\leq 10^{-5}$	$\leq 10^{-6}$	$\leq 10^{-7}$	$\leq 10^{-7}$

NOTE 1 – Network packet loss rate requirements of strong-interaction cloud VR services in FEP are based on experimental results.

NOTE 2 – Network packet loss rate requirements of strong-interaction cloud VR services in CEP, IEP and UEP are based on theoretical calculation.

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