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Recommendation

ITU-T H.431.1 (01/2024)

SERIES H: Audiovisual and multimedia systems

Infrastructure of audiovisual services – Telepresence, immersive environments, virtual and extended reality

Functional architecture for cloud virtual reality systems

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Recommendation ITU-T H.431.1

Functional architecture for cloud virtual reality systems

Summary

Recommendation ITU-T H.431.1, together with its related Recommendation ITU-T F.746.14, specifies the functional architecture of cloud virtual reality systems. It describes the overall functional architecture including control layer, resource layer, network layer, terminal layer, operation, administration and management, and security. This Recommendation also describes the basic functions of each layer, such as unified scheduling/technology integration/content distribution of the control layer, cloud-based operation on the resource layer and high-quality transmission by the network layer. The cloud virtual reality (VR) content can be run concurrently based on the cloud and is distributed to the terminal for presentation.

History [*]

Edition	Recommendation	Approval	Study Group	Unique ID
1.0	ITU-T H.431.1	2024-01-13	16	11.1002/1000/15764

Keywords

Cloud virtual reality, functional architecture, virtual reality.

[*] To access the Recommendation, type the URL https://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

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1 Scope

This Recommendation specifies the functional architecture for cloud virtual reality systems, and includes an overview of the functional architecture for cloud virtual reality systems as well as a description of the respective functions.

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.

[ITU-T F.746.14] Recommendation ITU-T F.746.14 (2022), *Requirements and reference framework for cloud virtual reality systems*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following term defined elsewhere:

3.1.1 operations latency [ITU-T F.746.14]: The time it takes for the entire process from the terminal issuing a control command to the application content responding to the operation request and completing output.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AAC Advanced Audio Coding

AI Artificial Intelligence

APP Application

AVI Audio Video Interleave

AVS3 Audio Video Coding Standard 3

CDN Content Delivery Network

CMAF Common Media Application Format

CPU Central Processing Unit

DRB Data Radio Bearer

FMP4 Fragmented MP4

FOV	Field of View
gNB	The Next Generation Node B
GPU	Graphics Processing Unit
HTTPS	Hypertext Transfer Protocol Secure
IPsec	Internet Protocol Security
L2TP	Layer 2 Tunnelling Protocol
MP3	Moving Picture Experts Group Audio Layer III
MPEG	Moving Pictures Experts Group
OA&M	Operation, Administration and Management
OMAF	Omnidirectional Media Application Format
OpenVPN	Open Virtual Private Network
PPTP	Point-to-point Tunnelling Protocol
QoS	Quality of Service
RTMP	Real Time Messaging Protocol
SFTP	Secure File Transfer Protocol
SLA	Service Level Agreement
SRT	Subrip Text
STL	Standard Template Library
TSP	Truncated Square Pyramid projection format
VR	Virtual Reality
WAV	Waveform Audio File
Webvtt	The Web video text tracks format

5 Conventions

None.

6 Overview

With the concept of the metaverse rising, virtual reality (VR) as one of the basic technologies, has attracted more and more attention from the industry. VR technology is the basis for the construction of panoramic, three-dimensional and smooth interactive digital scenes in the metaverse. For the real-time multi-user remote online interactions and VR applications with large amounts of computation, the cloud mode or cloud operation and terminal collaboration is an optimal way to realize them. Therefore, cloud VR will undertake more and more important tasks for the VR ecosystem.

Cloud VR, which is based on cloud architecture and utilizes cloud capabilities, can effectively shield terminal differences, reduce the difficulty of application development, lower some specific industry entry barriers and promote the industry business chain cooperation.

[ITU-T F.746.14] provides a reference framework and basic requirements for cloud VR systems. Based on them, it is necessary to analyse more systematically the functional architecture of cloud VR systems.

Cloud VR systems are the end-to-end service mode of VR based on cloud. Cloud VR systems are achieved based on unified resource and capacity control scheduling, operation, administration and management (OA&M) and security management, cloud resource computing power supply, low latency, high bandwidth and high security network transmission, and terminal's presentation. It is necessary to clarify the functional architecture of cloud VR systems, including the overall architecture of cloud VR systems and the functional components of cloud VR services.

This Recommendation can lay the foundation of functional architecture for other related standards of cloud VR systems.

7 Functional architecture for cloud virtual reality systems

The functional architecture for cloud VR systems is illustrated by Figure 7-1.

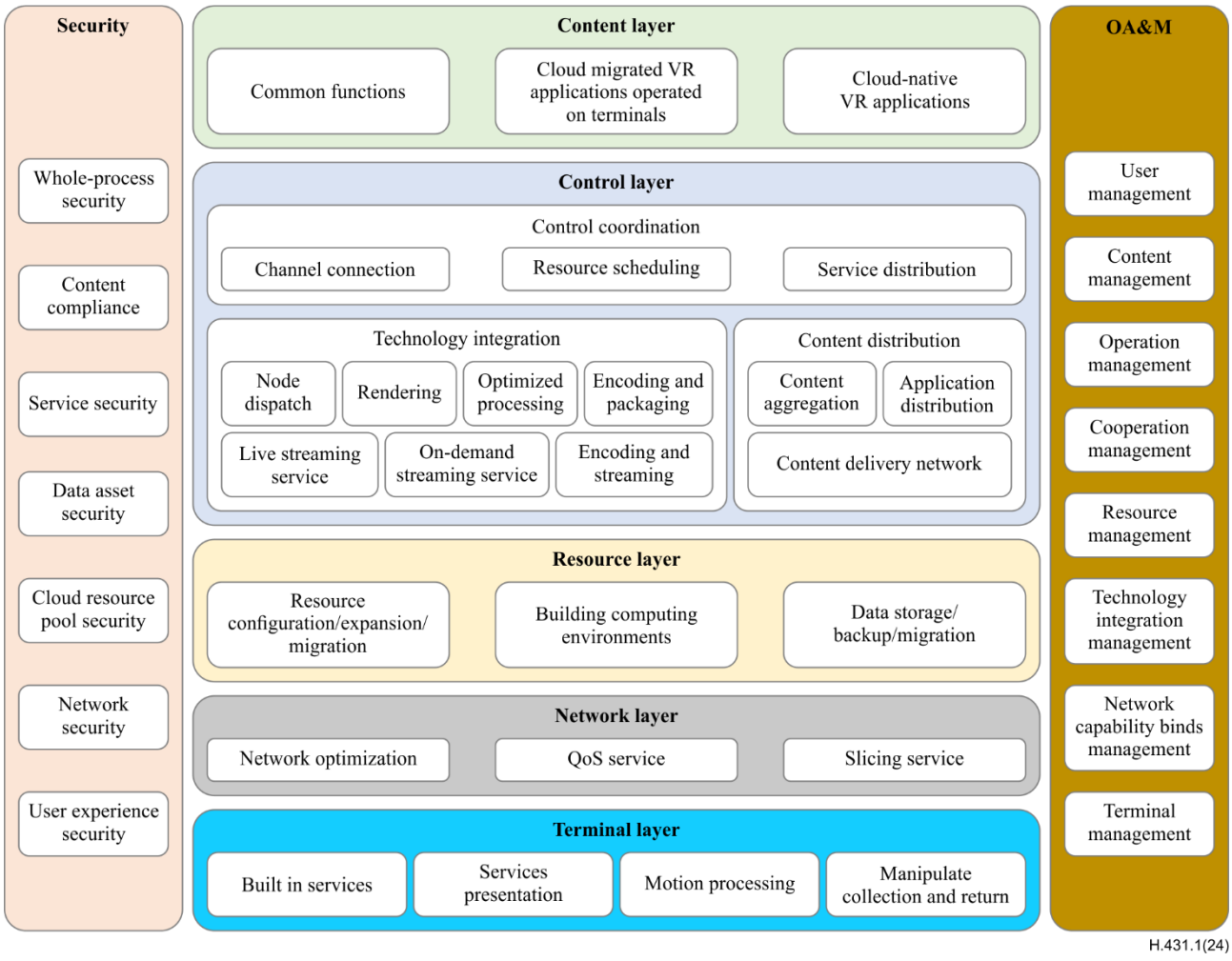

Figure 7-1 – Functional architecture for cloud VR systems

The main function of the content layer of cloud VR systems is to support the common functions and the cloud-based operation of VR applications. From the perspective of operation modes, cloud VR applications mainly include cloud migrated VR applications operated on terminals and cloud-native VR applications.

– Cloud migrated VR applications operated on terminals are VR applications installed, loaded, operated, manipulated and displayed in the software and hardware environment of a VR terminal for the purpose of local operation of the VR terminal. To realize cloud-based operation, such VR applications need to carry out operation adaptation to cloud software and

hardware resource pool, data encapsulation / remote distribution of operation results, and acquisition / response to terminal remote control.

– Cloud-native VR applications run natively in the cloud, which can effectively connect with common cloud operating environments, and its installation, loading, operation and other related processes can effectively adapt to cloud resources and application data sharing mechanisms. It can effectively improve the utilization of cloud software and hardware resources, and has the advantage of content data resource sharing. Cloud-native VR applications also need to have access to remote control acquisition / response with the terminal side.

The control layer provides the functions of control coordination, technology integration, content distribution, etc.

– The control coordination schedules the resource layer including resources like cloud computing power resources according to the cloud VR operation requirements, completes the docks and distribution of various channels of cloud VR services, and connects the cloud VR terminal to realize remote manipulation mapping.

– The technology integration provides various cloud operation capabilities, including two scenarios named video-based scenarios and graphics service-based scenarios, corresponding to cloud VR weak interaction scenarios and strong interaction scenarios respectively. On the video-based scenarios, it involves services including real-time online live broadcast and offline on-demand through adaptive transcoding and encapsulation between different audio and video formats according to different applications' characteristics and terminal requests. Video-based scenarios generally belong to the category of weak interaction scenarios but can also be reflected in some strong interaction scenarios or strong and weak compatible scenarios. On the graphics service-based scenarios, it includes the nearest, efficient and reliable online operation for terminal users through the cloud-side coordinated service node dispatch as online graphics rendering, encoding and streaming, then the media processing results (such as graphics and sound) with audio and video mode transmitting to terminals.

– The content distribution function is a cross function of video-based scenarios and graphics service-based scenarios, which provides content transmission services bridging cloud side and terminal side based on different distribution channels, such as content aggregation, application distribution. At the same time, as one function of content distribution, the content delivery network is necessary for video-based scenarios.

The resource layer provides computing power for cloud VR based on cloud resource pools. It builds computing environments such as virtual machines, containers or application virtualization to operate on cloud-based VR functions. At the same time, it provides the functions of resource configuration/expansion/migration and data storage/backup/migration which can adapt to changes in operating conditions.

The network layer provides the communication capabilities for cloud VR, such as quality of service (QoS) service, slicing service, network optimization, etc.

The terminal layer provides built-in services of cloud VR based on various terminal types such as VR mobile phone, VR all-in-one machine and VR split machine, such as cloud VR service clients/applications (APPs), plug-ins/SDKs, etc. It also provides service presentation on the terminals and collects manipulations of the terminals to return the control layer.

The OA&M provides centralized operating, management and maintenance functions of cloud VR, such as the managements of content, user, technology integration, operation, resource, network capability docks and terminal.

The security of cloud VR provides multi-dimensional security mechanisms, such as the securities of content, service, data, cloud resource pool, network and user experience.

The above only gives a preliminary introduction to the module's functions of each layer of cloud VR. Detailed explanations are given in clause 8.

8 Functions of the Content layer for cloud virtual reality systems

8.1 Common functions

It provides function docks for cloud VR contents, such as security assurance, authentication docks, billing integration, data synchronization and terminal control connection to effectively implement platform-based operation, maintenance and management.

– Security assurance: It provides compliant copyrights as well as safe and reliable operation mechanisms for the contents.

– Authentication docks: It provides authentication mechanisms for the contents by docks.

– Billing integration: It integrates different payment methods and payment channels, which provide docks for VR contents through interfaces and other methods.

– Data synchronization: It synchronizes operation data through an open data interface to help improve service quality.

– Terminal control connection: It realizes the operation of VR contents according to operation instructions uploaded by the terminal side and parsed by the platform in order to provide real-time experience of cloud VR contents.

8.2 Cloud migration functions of VR content based on terminal operation

VR content based on terminal operation have the characteristics of independent terminal operation and data processing. To realize the cloud operation of this type of contents, it is necessary to modify the cloud operation adaptation to support the interception/encapsulation of operation data such as graphics / sound and flexible loading of progress data.

– Cloud operation adaptation: It changes terminal-based operation mode to cloud-based operation mode which is able to operate VR application based on qualified cloud environment. By removing the restrictions on terminal operation and concurrent operation of such VR applications, it can realize multi-channel concurrent operation and remote operation in the cloud.

– Support interception / encapsulation of running data (such as graphics/sounds): It converts VR applications based on localized result outputs into shielded display mode. It supports interception and encapsulation of operation graphics and sound results, which lays the foundation for subsequent distribution to the terminal side.

– Flexible loading of progress data: It supports cloud VR progress data acquisition and loading across cloud-based operation environments including physical real machines, virtual machines and containers.

8.3 Functions of cloud-native VR applications

The cloud-native VR applications do not require cloud operation adaptation, and can provide relevant graphics/sound and other operational data interception/encapsulation and flexible loading of progress data based on cloud native. This type of cloud VR contents can also realize multi-dimensional sharing of computing resources in the cloud resource pool and data processing results, especially for graphics applications.

– Graphical resource classification processing: The cloud VR applications based on the unified identifiers of the terminal service requests, such as coordinate information, environmental variables and user identity, divide graphics resources into general-purpose graphics resources for multiple people and exclusive graphics resources for personal uses. General-purpose

graphics resources are resources used by multiple users or multiple scenarios. Exclusive graphics resources include interactive scenes, real-time changing light and shadow properties, etc.

– General graphics resource processing: Centralized and unified processing by means of real-time or pre offline processing, which obtains the current display screen and surrounding associated graphics resources based on the user terminal request, marks and carries out relevant coordinate information and environmental variables identification for distribution and sharing to multiple user terminals.

– Exclusive graphics resource processing: Based on the mutually independent operating environment, it completes the relevant logic operation and graphics rendering processing for the corresponding user terminals in real time, packs the user identity label, processed graphics resources and the synchronized associated sound effect for distribution to personal user terminal.

– Graphics resource integration: The terminal side integrates the general graphics resources and exclusive graphics resources delivered by the cloud based on the unified service identifier, re-matches the general graphics resources and the exclusive graphics resources for resource scheduling by feeding back relevant operation instructions, thus forming a closed loop processing.

9 Functions of the Control layer for cloud virtual reality systems

9.1 Control coordination

9.1.1 Channel connection

It implements the platform side docks of publicity and promotion channels and realizes the information synchronization of cloud VR service promotion. There are two ways of realization, such as link through the platform interface and independent completion of channels, so to support publicity and referral.

– Link through the platform interface: As the promotion channels active docks, the cloud VR platform side provides relevant data synchronization interfaces, the promotion channels reserve relevant publicity and promotion spaces according to agreed specifications, and the cloud VR platform actively publishes the publicity resources to the corresponding channels.

– Independent completion of channels: As the promotion channels independent completion, the cloud VR system provides relevant publicity resources, and then cloud VR service promotion information is independently released by the channel party on its own channel.

– Publicity and referral: After the completion of channel docks, it uploads relevant publicity pictures and texts, association of suggested links and other information to realize the function of publicity and referral.

9.1.2 Resource scheduling

It allocates corresponding running server resources in the service node content according to the terminal service request and content resource requirements.

– Capability matching: According to the resource occupancy of each server and the requirements of cloud VR graphics applications, it matches more suitable servers and selects one of them as the running server.

– Task distribution: It distributes task instructions for running cloud VR graphics applications to the running server which performs subsequent cloud rendering operation.

9.1.3 Service distribution

Based on cloud edge collaborative deployment, it provides unified management of cloud VR graphics applications and each rendering service node's installation/uninstallation/update.

– Unified management: It provides unified deployment strategies to realize graphics application deployment and debugging of each rendering node.

– Application deployment: It pushes the cloud VR application to each rendering node and completes the installation of the server to which it belongs.

– Application debugging: It tests and optimizes the entire service process including cloud import, operation, rendering and encoding streaming for the deployed VR application (e.g., graphics application).

9.2 Technology integration

9.2.1 Node dispatch

9.2.1.1 Service node call

Under the unified coordination of platform management functions, each node needs to have management and allocation functions of related node resources, such as monitoring operating status of the computing environment, deployment content management.

– Node resource management: It manages software and hardware resources in the rendering service node, including hardware resource management, software environment management, deployment content management, etc.

– Hardware resource management: It performs operations like statistics, classification, removal, addition and update for the hardware of each server in the node, such as central processing unit (CPU), graphics processing unit (GPU), memory, storage and other hardware resources.

– Software environment management: It performs statistics, version and security management as well as related security hardening, version update and reinstallation operations for the software resources of each server in the node, such as operating system, graphics environment, virtual machine/container, etc.

– Deployment content management: It makes statistics on the content list, version status and capability requirements, and provides operation functions such as version upgrade and content removal for the cloud VR graphics contents deployed on each server in the node.

9.2.1.2 Data backup and migration

It is performed during the operation process to ensure the continuity of cloud VR graphics application services in the event of a failure, so that the service can be quickly migrated.

– Data backup: During the running process of cloud VR graphics applications, related progress files have minute-level real-time storage and other server backup functions.

– Service migration: When the VR graphics application fails, it can quickly migrate the service to other servers and restart it.

9.2.1.3 Synchronization and coordination

To reduce the service delay, the platform side adopts the collaboration mode with the central cloud unified scheduling and edge node service. Since it involves the coordination and synchronization of multiple edge nodes, it is necessary to adopt a timing control mechanism for the interaction process of multi-user/multi-edge nodes to ensure the synchronization of remote interaction between multiple VR terminals.

– Unified interaction and coordination: To accurately schedule the multi-user remote interaction relationship in cloud VR applications, the central cloud formulates the strategy of combining interactive logic information and user-specific logic information.
    - The logic with interactive attributes of multi terminals and multi edge nodes is the interactive logic, and the related individual logic of terminal users is regarded as the user-specific logic of the terminal.
    - This strategy is distributed to the edge nodes. The interactive associated edge nodes divide the uploaded terminal user logical information into user-specific logic information and interactive logic information according to the above strategy.
    - At the same time, relevant edge nodes synchronize associated interaction logic information to the central cloud for unified real-time synchronization.
– Real time synchronization processing: The central cloud periodically predicts the relevant delay in the next period through time series linear programming methods based on the network historical link delay data which the central cloud monitored in the process of sending down interactive logic information to the edge nodes.
    - According to the delay length of the prediction results or the network historical link delay data, the central cloud groups the edge nodes and generates the corresponding synchronization time-series rules which are set to different edge nodes group.
    - For edge nodes group with short delay, the interactive logic information will be sent later than other edge nodes groups.
    - By analysing the interactive logic information, the central cloud identifies the users participating in the interaction and the user related edge nodes, and completes the interactive logic information distribution according to the synchronization timing rules, so that the interactive logic information approximately arrive at related multiple edge nodes synchronously, realizing the synchronization of multi-party interaction.

9.2.2 Rendering

Rendering process includes graphics application start-up, hardware resource allocation, graphics application running, output data interception, graphics data transmission.

– Graphics application start-up: In response to the remote concurrent graphics application's service requests including graphics application display/graphics application pause and graphics application exit, then multiple parallel application running instructions are initiated.
– Hardware resource allocation: The GPU hardware resources in the cloud are divided by the GPU hardware driver layer's hardware resources calling interface, according to the requirements of various concurrent applications, so as to allocate independent hardware resources from the same graphics card entity to each application. Among them, according to the running instructions of multiple concurrent applications, the GPU virtual running container is set up and managed. Under the condition that the service request is graphic application display and graphic application pause, a GPU virtual running container of graphic application is constructed; In the case that the service request is that the graphics application exits, the GPU virtual running container allocated for the graphics application is released.
– Running a graphics application: Based on the allocated hardware resources, run multiple parallel applications and complete the rendering of their respective graphics.
– Output data interception: Obtain the hardware resource address used by each application through the path addressing mechanism, and based on the obtained address, the rendered output data is directly intercepted at the bottom of the hardware.
– Graphics data transmission: Streaming the rendered output data, it is transmitted to the remote users who initiated the concurrent graphic applications, so as to directly display the graphics corresponding to the graphic applications on the terminals used by the users. Before

streaming, in order to achieve the optimal output structure, it is necessary to determine the maximum number of frames and code stream of graphic data transmission according to the user's network conditions before streaming, and package the rendered output data in real time.

9.2.3 Optimized processing

9.2.3.1 Layered optimization

It adapts to the focus's change of attention from cloud VR terminal users, and intelligently matches video quality according to the layered partition mode, which can effectively reduce the pressure of cloud deployment and improve network carrying capacity.

– Focus acquisition: The terminal user sends the focus of the current cloud VR application' attention to the server of control layer on the cloud, so that the cloud server performs video layering and partition processing according to the obtained focus.

– Video layered partition: In order to reduce the transmission pressure of the media stream, the cloud processing server divides the VR video image into the core area associated with the current focus and the surrounding area adjacent to the core area, and performs layered processing of the VR video according to the obtained focus, including low-quality base layer video and high-quality enhancement layer video. The basic layer video range transmitted by cloud includes the core area video of the base layer and the surrounding area video of the base layer; the enhancement layer video range transmitted by cloud includes the core area video of the enhancement layer and the surrounding area video of the enhancement layer.

– Processing result presentation: The terminal obtains the enhancement layer video of the core area and the base layer video of the surrounding area delivered by the cloud server, then splices the enhancement layer video of the core area and the base layer video of the surrounding area in order to get the spliced result, and displays the spliced result on the terminal; at the same time, the edge node near the user terminal obtains the enhanced video of the surrounding area and stores it in the cache for subsequent terminals.

– Change prediction: When the position of the user terminal is offset according to the information collected by the sensor, the terminal predicts the focus' change based on artificial intelligence (AI) and uploads the predicted result of the focus' change to edge node, in order to get the enhancement layer video of the surrounding area from the edge node which correlates the prediction results of the focus' change.

  ○ The edge node obtains the enhancement layer video of the surrounding area which is adjacent to the enhancement layer video of the core area associated with the current focus, and combines the enhancement layer video of the core area with the enhancement layer video of the surrounding area associated with the prediction result from the cloud according to the prediction change, then sends it to the terminal in time, so that the terminal side can get the enhancement layer video of the surrounding area associated with the prediction result from the edge node, combine the core area video of the enhancement layer and the surrounding area video associated with the focus transformation prediction result of the enhancement layer for display.

  ○ Before displaying the combined result, the terminal calls the base layer video of the surrounding area associated with the focus change prediction result from the local cache for display.

– Loops processing: When it is determined that the position of the user terminal stops shifting according to the information collected by the terminal sensor, the new focus of the current user is repeatedly sent to the cloud server, so that the cloud server performs layered and partitioned processing on the video again to form an overall closed loop.

9.2.3.2 Block optimization

First, the cloud server of the control layer obtains the target multimedia data to be sent to the terminal; then, the cloud server performs the target multimedia data rendering based on the terminal device information such as the terminal's field of view (FOV), screen refresh rate and screen resolution of the terminal equipment information or the terminal capability and the network status of the terminal status information to get the rendered multimedia data. Finally, the rendered multimedia data will be sent to the terminal.

– Image blocking: The cloud server first obtains the multimedia data to be sent to the terminal, and divides each frame of the multimedia data into blocks according to the terminal device information, then obtains the data of each frame's multiple blocks. The cloud server selects several central blocks as the central display area according to the terminal's FOV and screen display area, and other blocks as the non-central display area, which is convenient for subsequent optimization processing.

– Tuning process: Based on the original multimedia image resolution and frame rate, the cloud adjusts and optimizes the resolution and frame rate of each frame of the target multimedia data according to the terminal device information, then generates the rendered multimedia data. Especially for the central display area, under the premise of using the network transmission capability, when the display resolution and frame rate of the terminal are higher than the original level, the corresponding quality improvement rendering processing is adopted. If it is lower than the original level, the corresponding quality reduction treatment shall be adopted.

9.2.4 Encoding and packaging

9.2.4.1 Encoding

It supports various common cloud VR projection methods, adopts compliant audio and video encoding formats, to complete the encoding process.

– Projection methods: It should use supported common projection formats to complete cloud VR panoramic projection, such as omnidirectional media application format (OMAF) ERP, truncated square pyramid projection format (TSP), CUBE, etc.

– Video encoding: It should use compliant video encoding formats to complete video encoding, such as ITU-T H.264 [b-ITU-T H.264], ITU-T H.265 [b-ITU-T H.265], audio video coding standard 3 (AVS3), etc.

– Audio coding: It should use compliant audio encoding formats to complete audio encoding, such as Moving Picture Experts Group Audio Layer III (MP3), advanced audio coding (AAC, waveform audio file (WAV), etc.

9.2.4.2 Packaging

It supports the use of compliant packaging formats, packages cloud VR multimedia-related video/audio/subtitles and other information into a single file, and supports large file transfer protocols.

– Large file transfer: It should support the large file transfer function and encapsulate the corresponding combined transfer protocol, such as real time messaging protocol (RTMP), secure file transfer protocol (SFTP), etc.

– Subtitles addition: It has the function of using compliant formats to complete subtitle addition, such as subrip text (SRT), the web video text tracks format (Webvtt), standard template library (STL), etc.

– Packaging function: It adopts a compliant packaging format to complete the packaging of multimedia files, such as MPEG-2 TS, fragmented MP4 (FMP4), common media application format (CMAF), etc.

9.2.5 Live streaming service

9.2.5.1 Material collection

In the process of audio and video data material collection, it is necessary to have 360-degree collection, real-time data interaction, etc.

– 360-degree acquisition: It supports camera multi-camera shooting or VR dome stand-alone shooting methods, and the viewing angle has the ability to cover 360-degree panorama.

– Real-time data interaction: Cameras of cloud VR systems can collect the corresponding audio and video data in real time, combine the corresponding camera position and other information to transmit them to the splicing processing unit in real time.

– Panoramic stitching: The splicing processing unit, including the server where the data source is local or the nearby edge node server, completes the splicing function of live audio and video in accordance with OMAF, TSP, CUBE and other compliant panoramic projection methods. After the panoramic stitching is completed, the encoding and packaging functions are docked.

9.2.5.2 Live broadcast sharing

With 360-degree panoramic images, spatial sound effects, etc., it brings immersive cloud VR live viewing experience, such as real-time ball games, sports meetings, concerts, etc.

– Live source access: It supports a variety of VR live source access, and provides functions such as video pushing, streaming and output playback.

– Function expansion: In order to adapt to different network conditions and terminal types, it supports functions such as real-time transcoding, multi-bitrate output and content distribution capabilities. In order to facilitate user review, it supports automatic generation of on-demand streaming files.

– Live monitoring: In order to ensure the legality of live streaming content, it should have the function of reviewing the content of the stream, and realize automatic alerts for illegal content such as pornography, gambling, politics, drugs, violence and terrorism.

9.2.6 On-demand streaming service

Based on functions such as resource distribution, video transcoding, and screen display range switching, it provides users with cloud VR on-demand services including movies, TV dramas, variety shows, documentaries, sports events, concerts.

– Resource distribution: Adopting content delivery network (CDN) technology, supporting on-demand resources in different video formats, and utilizing various transmission protocols, it has the function of distributing resources nearby for multiple users.

– Video transcoding: In order to meet the needs of different playback environments, support the transcoding function between cloud VR on-demand video resources with different encoding formats, resolutions and projection formats.

– Screen display range switching: In order to flexibly adapt to terminal processing and network transmission capabilities, it has the processing and transmission capabilities of panoramic and FOV screen range switching.

9.2.7 Encoding and streaming

For strong interaction scenarios such as games, it is necessary to obtain the screen resources and audio resources output by the cloud VR content in real time, and then stream/distribute them with the corresponding transport protocol after synchronous encoding of audio and video.

– Sound resource acquisition: Through corresponding hook mechanism interception, virtual sound cards and other technologies, it supports multi-channel access to real-time audio and

sound effects resources output by cloud VR applications, ensuring an immersive sound experience.

– Simultaneous audio and video encoding: For the acquired image and sound resources, the video encoding and audio encoding are completed synchronously in real time by adopting compliant encoding methods.

– Streaming and distribution: For the encoded audio and video resources, they are encapsulated as one or more multimedia streams according to the corresponding transmission protocol, and delivered to users based on network addressing.

9.3 Content distribution

9.3.1 Content aggregation

It supports a variety of different types of cloud VR content and service modes, and completes content deployment with flexible injection methods.

– Content type: It supports a variety of different cloud VR content such as videos, animations and games, and has the ability to build its cloud operation.

– Service mode: It supports RTMP and other live broadcast protocols, SFTP / hypertext transfer protocol secure (HTTPS) and other offline protocols, and can provide live broadcast, on-demand and other service modes.

– Injection mode: It has a flexible content injection method, such as real-time content injection and offline content injection.

– Content deployment: With one-stop cloud edge deployment capability, it can achieve rapid injection of cloud VR content.

9.3.2 Application distribution

In order to achieve cloud VR content and services to quickly reach users, it is necessary to have a variety of distribution mechanisms, distribution channels and service association methods.

– Distribution mechanisms: As a cloud VR service and content to reach the user's method, it needs to support centralized distribution and distributed distribution. The central distribution is a distribution mode where the control layer is managed uniformly and serves as the content distribution source; the distributed distribution is a distribution model with decentralized multiple sources, and the control layer only provides authentication and supervision.

– Distribution channels: Equipped with various methods such as graphic and text links, download addresses, and page displays, it can be distributed to users through various channels such as websites, social tools, aggregation platforms, and embedded pages.

– Service association methods: It has the function of supporting the interconnection of cloud VR content and cloud VR systems services during the distribution process.

9.3.3 Content delivery network

For cloud VR content, CDN adopts cloud-edge collaboration, with central nodes providing functions such as distribution, scheduling and transmission. Edge nodes provide services and accelerate content transmission nearby, functions such as distributed deployment, load balancing, flexible transmission and error correction capability.

– Distributed deployment: For cloud VR content, it provides distributed networking services, content storage and streaming media services.

– Load balancing: For cloud VR content, it provides load balancing services of streaming media services.

– Flexible transmission: For cloud VR content, it provides functions such as transparent transmission, full-view transmission and FOV transmission.

– Error correction capability: For cloud VR content, it provides error correction functions such as data integrity and audio/video synchronization.

10 Functions of the Resource layer for cloud virtual reality systems

10.1 Resource configuration/expansion/migration

10.1.1 Resource configuration

In response to the operation requirements of cloud VR system services or applications, under the unified control of the control layer, the mapping of hardware resources and the call of software resources are realized, laying the foundation for the subsequent construction of the operating environment.

– Hardware resource mapping: According to the computing power requirements of related cloud VR system services or applications, it needs to call and configure hardware resources such as CPU, GPU and storage space.

– Software resource call: On the basis of the computing power to complete the hardware resource mapping, the corresponding process, virtual machine, container, physical machine are realized to lay the foundation for the subsequent operating environment.

10.1.2 Resource expansion

When the configured operating environment is insufficient, more resources need to be allocated to expand related computing power and provide functions such as real-time expansion and on-demand configuration.

– Real-time expansion: It can respond to resource expansion requirements in real time, timely implement the configuration of related software and hardware resources, and achieve the timely supply of resources without affecting cloud VR functions or application quality.

– On-demand configuration: It can provide relevant expansion resources according to the computing power requirements such as computing, rendering and storage, as well as various software operating environment requirements.

10.1.3 Service migration

When a cloud VR service or application runtime environment is abnormal, it is needed to reconfigure new resources to complete the corresponding migration.

– Resource switchover: When service migration is required, the resources of the original hardware and software running environment need to be released, and the reconfigured resources must be enabled at the same time to switch between the old and new resources.

– Progress synchronization: When switching resources in the running environment, it is necessary to complete the synchronization of the corresponding progress files of the corresponding cloud VR services or applications between the old and new resources in a timely manner to ensure seamless switchover.

10.2 Building computing environments

For different service functions and applications of cloud VR systems, it provides multiple operating environments such as virtual machine hosting, container hosting and physical machine hosting.

– Virtual machine hosting: Based on the virtual machines related to the cloud resource pool, it realizes the concurrent hosting of cloud VR system function modules and applications, and has virtual machine start/migration/shutdown, service and content import/run/pause/exit under the unified control of the control layer, and provides the progress files' storage function.

– Container hosting: Based on the containers related to the cloud resource pool, it realizes the concurrent hosting of cloud VR system functional modules and applications, and has container start/migration/shutdown, service and content import/run/pause/exit under the unified control of the control layer, and provides the progress files' storage function.

– Physical machine hosting: Cloud VR applications or services with complex computing and graphics rendering need to run in the exclusive mode of physical machines, realize functions such as service and content import/run/pause/exit under the unified control of the control layer, and provide the progress files' storage function.

10.3 Data storage/backup/migration

– Operation progress storage: According to the set cycle, the running progress files related to cloud VR functions or content are stored for migration in case of failure; when the cloud VR service or application exits, the final progress files are stored so that it can be synchronized when it is rerun.

– Log storage: During the operation of cloud VR, the operation logs related to cloud VR functions or content are needed to store so that it can be tracked relevant alarms and faults.

– Operational data storage: During the operation of cloud VR, data such as the running status of related services or content, and user behaviour without privacy need to be stored in an encrypted manner.

– Data backup: In order to ensure the effectiveness of data storage, it is necessary to provide a domain-specific data backup mechanism to avoid the situation that the data cannot be recovered when the domain fails.

– Data migration: When the service is migrated or rerun, the relevant progress data needs to be synchronized and migrated; when the resource pool related to the resource layer is maintained or shut down, the corresponding data needs to be migrated to the new resource pool.

11 Functions of the network layer for cloud virtual reality systems

11.1 Network optimization

11.1.1 Network acceleration

To provide end-to-end network acceleration services for users based on network capabilities, it is necessary to complete authority authentication based on the user's application to be accelerated. If the authentication is passed, it performs the manipulation step of providing the acceleration service for the application to be accelerated. In the network acceleration service's process, first, the user side's network equipment monitors the user's application traffic; then, identifies the traffic of the pre-configured application to be accelerated from the monitored application traffic; and then, self-adaption selects acceleration link; finally, the acceleration service is provided for the application to be accelerated based on the acceleration link.

In the authentication process, the network device on the user side needs to send a service authority authentication request to the management server with the information of the user and the application to be accelerated, so that the management server can confirm whether the user has the authority to enjoy the service of accelerating the related application to be accelerated. And then the network device on the user side receives the service permission authentication response returned by the management server.

According to the service permission authentication response, the service permission authentication result of the user to accelerate the application is determined. Preconfigure the description information of the application to be accelerated in advance, includes the application name, server address or application type.

– Network monitoring: The user side's network equipment real-time monitors the user's application traffic, and determines whether the network is congested according to the real-time traffic monitoring result; when the congestion occurs, and then judges whether the traffic on the user side has an abnormal traffic that greater than the preset value. When it is determined that there has no abnormal traffic, the user is prompted that the network is abnormal, or the user is prompted to disconnect the current network connection and reconnect the network. When it is determined that there is an abnormal traffic, speed limiting or closing the abnormal traffic is performed, in order to optimize user network outlet bandwidth. And after limiting the speed or closing the abnormal traffic, the step of providing acceleration service for the application to be accelerated is executed.
– Identify the application to be accelerated: The description information of the application to be accelerated is matched with the description information of the monitored application traffic, so as to identify the pre-configured traffic of the application to be accelerated from the monitored application traffic.
– Select acceleration link: Testing the network service quality of the acceleration link between the user side network equipment and each acceleration proxy server, in order to select acceleration link.
– Provide network acceleration service: The acceleration link with the best network service quality is used as the acceleration link of the application to be accelerated.
– Acceleration execution: Provide acceleration service for that application to be accelerated based on the selected acceleration link, and establishing a link between the user-side network access device and the corresponding acceleration proxy server through point-to-point tunnelling protocol (PPTP), Layer 2 tunnelling protocol (L2TP), Internet protocol security (IPsec) or open virtual private network (OpenVPN).

11.1.2 Network link optimization

11.1.2.1 Flexible link optimization selection

For different service types of cloud VR systems, it provides the optimization functions of network links such as shortest path optimization, optimal bandwidth path optimization, and comprehensive optimal path optimization.

– Shortest path optimization: In the scenarios where extremely low latency is required for latency-sensitive content and remote control instruction upload in cloud VR systems, the shortest path transmission is selected among multiple network links to achieve the lowest transmission delay.
– Optimal bandwidth path optimization: For service scenarios with high bandwidth in cloud VR systems, the link with the most sufficient bandwidth is selected from the multiple network links to meet the requirements of high-channel transmission.
– Comprehensive optimal path optimization: For scenarios with both latency and bandwidth requirements in cloud VR systems, it is necessary to comprehensively integrate the transmission requirements at the service level and the transmission capabilities of the current links of the network, comprehensively consider the indicators such as delay, bandwidth and reliability, to select the comprehensive and optimal link.

11.1.2.2 Intelligent selection path

– Determine the shortest path topology: In order to meet the transmission requirements of cloud VR, based on multiple path selection criteria such as latency, reliability and jitter corresponding to the network data flow to be transmitted, the shortest path algorithm is used to search for the shortest path in parallel for each path selection criteria, and multiple shortest network paths corresponding to each path selection criteria are obtained and determined.

Based on multiple shortest network paths corresponding to each path selection criteria, the shortest path topology corresponding to network data flow are determined.

– Determine the network transmission path: The breadth-first search algorithm is used to conduct multi-criteria routing search based on the shortest path topology to obtain and determine the target network path. In the process of multi-criteria route selection search based on Breadth-first search algorithm, the network transmission constraints, such as the transmission performance requirements of network data flow, are obtained and used along with the constraints of to each path selection criteria to obtain the target network path.

– Network path transmission: Allocate transmission bandwidth to the target network path of each network data flow according to the network transmission constraints, realize based on the transmission bandwidth allocated for the target network path, the network data flow is transmitted through the target network path.

11.1.3 Multi stream parallel transmission

11.1.3.1 Multi stream transmission

For cloud VR systems service scenarios with ultra-large bandwidth requirements, in order to avoid congestion and heavy burden caused by single link transmission, multi-stream parallel transmission is required. At the same time, in order to avoid the user experience problem caused by the loss of key frames of multimedia streams, redundant transmission of key frames is also required. Moreover, in order to provide the utilization rate of network transmission data, it is necessary to have the function of multi-person universal data sharing and multi-stream sharing while multi-stream parallel transmission.

– Multi-stream parallel transmission: After the control layer of the cloud VR system completes the corresponding multi-stream encoding processing, the network layer needs to allocate the corresponding multiple network links to provide the network parallel transmission function in real time.

– Redundant transmission of key frames: For key frames that play an important role, the network layer provides a corresponding redundant transmission mechanism to realize the transmission of a streamlined data flow with key frames over another link.

– Multi-stream sharing: For multimedia streams with multiple people reused, the network layer provides a multi-stream multi-person addressing mechanism to realize multi-stream sharing transmission.

11.1.3.2 Optimization of multi-stream hierarchical transmission

In order to provide an optimized multi-stream transmission mechanism for cloud VR, it is necessary to determine the important service flow and ordinary service flow from the cloud-network service flows which require allocating cloud-network resources. The important service flow, e.g., the flow corresponding to area that the user is currently focusing on; the ordinary service flow refers to other service flows except important service flow. The priority of important service flow is higher than that of the ordinary service flow.

– Priority resource allocation: From the cloud-network resources, identify priority candidate paths that match the priority requirements of important service flow, such as bandwidth, latency and reliability. The priority target transmission path is also confirmed from the priority candidate paths, and its resource allocation information is determined, as the priority resource allocation information for important service flow.

– Determine the amount of resource redundancy: Determine the excess probability of priority service flow based on the historical network resource usage of important service flow. The excess probability is used to characterize the probability that the actual resource consumption of an important service flow exceeds the priority resource allocation. At the same time,

according to the excess probability, determine the amount of resource redundancy for important service flow.

– Obtain remaining resources: According to the priority resources allocate information and resource redundancy of important service flows, and obtain the predicted resource occupation of important service flow. In addition, remove the predicted resource occupation from the cloud-network resources to obtain and determine the remaining resources.

– Allocate other resources: Based on the remaining resources of the cloud-network resources, determine the relevant candidate paths that match the ordinary service requirements of the ordinary service flow. Determine the relevant target path from the candidate paths related to the ordinary service flow, and determine its corresponding the resource allocation information as the resources allocation information for the ordinary service flow.

– Complete multi-stream transmission: allocate relevant cloud-network resources for the important service flow and the ordinary service flow based on the priority resource allocation information of the important service flow and the resource allocation information of the ordinary service flow, and complete related multi-stream transfers.

11.2 QoS service

– QoS level classification: Based on the different application requirements of cloud VR, and the connection with the access network and bearer network capabilities, complete QoS level identification and labelling, as well as corresponding level classification, etc.

– QoS level guarantee: According to the corresponding QoS level, the corresponding QoS guarantee network transmission service is provided for cloud VR services.

11.3 Slicing service

Based on the requirements of the control layer, the network layer provides relevant service capabilities to realize network slicing services for the functions of the cloud VR systems, including functions such as slicing full-process service and slicing resource isolation guarantee.

– Network planning and evaluation: Through the analysis of service level agreement (SLA) requirements and network resources of cloud VR slicing services, the mapping from SLA requirements to resources and features is established, and SLA service capabilities are evaluated. In the evaluation stage, for cellular access networks, it is necessary to comprehensively consider wireless conditions such as signal-to-noise ratio, channel characteristics and other factors, as well as factors such as the geographical distribution of cloud VR terminals and traffic models.

– Differentiated scheduling: The network layer provides differentiated service SLA guarantee capabilities for different cloud VR systems services' requirements.

– Closed-loops guarantee: By evaluating and monitoring the relevant indicators of the cloud VR systems, the network layer can quickly adjust RAN resource scheduling or self-heal faults that affect SLA.

– Slicing resource isolation guarantee: According to the different service requirements of cloud VR systems, the network layer can flexibly provide data radio bearer (DRB) logical resource sharding, air interface spectrum resource sharding, and gNB-level resource sharding.

12 Functions of the terminals layer for cloud virtual reality systems

12.1 Build in service

Through different built-in methods such as AAP, SDK and H5 pages, the terminal built-in cloud VR services are completed, mainly including built-in identity authentication, built-in service remote call/run/pause/shutdown, and built-in operation and maintenance service.

– Built-in identity authentication: Through the docks of OA&M related user management and terminal management functions, built-in secure user identity, terminal information and other authentication capabilities to complete user registration/login/service permission authentication, terminal identification/content matching, etc.
– Service remote call/run/pause/shutdown built-in: After completing the relevant authentication, the docks control layer realizes the nearest service node allocated based on the terminal remote access resource layer, and completes the call/run/pause/shutdown operations of each functional module of the relevant cloud VR.
– Built-in OA&M service: Through the docks of OA&M-related OA&M management functions, online problem feedback, question answering, rights protection appeals, personal account management and other operations can be completed based on terminals.

12.2 Services presentation

After receiving the cloud VR multimedia stream delivered by the cloud, the terminal completes the output of the cloud VR system service through local audio and video decoding, audio and video synchronization, quality enhancement and stereoscopic output.

– Audio and video decoding: the terminal side supports at least one of the hardware decoding or software decoding methods, and uses ITU-T H.264, ITU-T H.265, audio video interleave (AVI), etc. formats to complete the audio and video decoding processing of multimedia streams.
– Audio and video synchronization: For the decoded video stream and audio stream, the sound and image are synchronized according to the corresponding method of the relevant frame.
– Quality enhancement: In order to achieve the best effect of local display, it is recommended to improve the clarity of cloud VR system services by increasing the number of frames.
– Stereoscopic output: The terminal completes the fusion stereoscopic output of image and sound by splitting the screen left and right.

12.3 Motion processing

In the process of using cloud VR, when movements such as turning the head and moving are generated, it is necessary to adjust and optimize the picture accordingly. According to the motion sensing data collected by the cloud VR terminal in the early stage of motion, the motion of the related cloud VR terminal is predicted and processed, and the predicted motion data is obtained. Through real-time interaction with the cloud server, the display device of the corresponding cloud VR terminal is controlled to display the target cloud VR display screen determined based on the above predicted motion data.

– Obtain picture offset: According to the predicted motion data, convert it from the coordinate system corresponding to the cloud VR terminal to the image coordinate system corresponding to the original cloud VR image, and determine/obtain the picture offset data. The picture offset data is used to characterize the offset of the VR picture caused by the motion predicted by the cloud VR terminal.
– Picture offset data processing: It is necessary to determine the conscious attribute of the movement, and carry out subsequent corresponding processing according to this attribute. If the offset of the cloud VR picture is determined to be less than the offset threshold that requires picture adjustment according to the picture offset data, it is determined that the motion of the VR terminal is caused by the user's unconscious movement, and there is no need for screen adjustment processing. If it is determined that the motion of the cloud VR terminal is not caused by the user's unconscious movement according to the picture offset data, it is determined whether the offset of the cloud VR picture is greater than the threshold that needs to be processed by the cloud server according to the picture offset data. If it is

determined that the offset of the cloud VR picture is greater than the threshold required by the cloud server according to the picture offset data, perform the steps of sending the picture offset data to the cloud server. If it is determined that the offset of the cloud VR picture is less than or equal to the threshold at which the cloud server needs to adjust the screenshot according to the picture offset data, and no need to send the picture offset data to the cloud server.

– Screen offset processing: Under the premise of meeting the needs of the cloud server to adjust the screenshot picture, the cloud VR terminal sends the picture offset data to the cloud server, in order to instruct the cloud server that adjusts the current screen capture range according to the picture offset data, and intercepts the original cloud VR image based on the adjusted screen capture range, so obtains and returns the adjusted cloud VR image, for the cloud VR terminal to display the corresponding target cloud VR picture on its display device according to the cloud VR image adjusted by the screenshot.

12.4 Manipulate collection and return

The manipulation process of cloud VR system services is initiated by the terminal, the remote manipulate functions are completed by collecting manipulate information, converting manipulate commands, and uploading manipulate commands in terminal side.

– Collecting manipulate information: The terminal integrates local sensor value changes and various control commands such as handle, touch screen, gesture, voice control, etc., to complete the collection of moving distance, movement direction/angle, height change and control key value and other information.

– Converting manipulate commands: According to the content and control correspondence set by the cloud VR control layer, the locally collected control information is transformed, including key-value correspondence, position movement and screen display area correspondence.

– Uploading manipulate commands: The terminal obtains the control information collection, control command conversion results, and uploads them to the service node corresponding to the cloud VR systems service in real time to complete the remote control process.

13 Functions of OA&M for cloud virtual reality systems

13.1 User management

The user side provides an account system for cloud VR services; the terminal side provides verification mechanisms, etc.

– User-oriented account mechanism: It provides functions including user account registration, service login authentication and service payment management for cloud VR services.

– Terminal access: It collects and analyses the hardware computing capability, VR local operating environment capability, screen display capability and local control capability of the access terminal and updates the terminal resource database at the platform side. By completing the terminal access management, a terminal resource library can be established, which lays the foundation of the subsequent realization of matching cloud VR application contents and cloud VR terminal capabilities. The function of chip computing provides capabilities like logical computing processing, graphics processing and local storage, etc. The function of VR local operating environment provides built-in VR operating framework, or middleware in the terminal with various models and versions. The function of screen display provides VR content display capabilities at the terminal side including resolution, refresh rate and field of view of display screen. The function of local control provides built-in or external capabilities like sensors, gravimeters and so on to compute data of user's action/movements for spatial positioning.

– Built-in service management: It completes built-in, version detection and optimization update of the cloud VR service by analysing and managing built-in cloud VR services of the terminal. The function of built-in cloud VR service completes localized installation of relevant cloud VR services for terminals that have not completed the cloud VR service built-in; The function of version detection detects and records the relevant version of cloud services built in the terminal; The function of optimization update completes the update of the latest version by automatically delivering the optimized version, when the version of the built-in cloud VR service in the terminal is low.
– Control methods docks: It completes the control and association of terminal-related sensors, peripheral equipment and positioning equipment. It records, synchronizes and associates information related to terminal control through the platform side, laying a solid foundation for remote control.

13.2 Content management

It provides functions of compliance assessment, content injection and cloud-based processing for cloud VR contents so that they are able to run based on cloud resource pools.

– Compliance evaluation: It automatically or manually evaluates the copyright legitimacy, user experience effectiveness and functional reliability of relevant cloud VR contents to ensure that they meet the online requirements.
– Content injection: It completes the VR content platform injection process, such as installing files to import into the platform.
– Cloud-based processing: VR contents running in terminals need connection debugging of the cloud operating environment and remote control to ensure that the terminal is able to utilize capabilities of cloud resource pool on the platform side to run VR contents.

13.3 Operation management

For operation and maintenance personnel of the operation, it provides comprehensive management functions of system configuration, operation and maintenance monitoring, data management, service strategy, etc.

– System configuration: It provides installation and deployment of management and service related software, software updates, management permission control and other functions for cloud VR platform.
– Operation and maintenance monitoring: It provides management control of platform related software resources, hardware resources and cloud VR service functions, and alarm for various hidden dangers during the operation of the platform.
– Data management: It provides cloud VR related operation data management, including data verification, data processing, data desensitization, data normalization, data mining and result display.
– Service strategy: It provides strategic functions for product packaging, sales pricing, preferential settings and so on for cloud VR services.

13.4 Cooperation management

For cloud VR content providers, it provides management functions such as operation tracking and market settlement, etc.

– Operation tracking: It provides the operation status of cloud VR contents to content providers who can modify and improve cloud VR contents according to actual market feedback.
– Market settlement: It provides the actual market revenue of relevant cloud VR contents, and it is recommended to have the function of online settlement on time.

13.5 Resource management

It provides management functions of computing resources, storage resources, data resources, etc.

– Computing resource management: It provides real-time monitoring of the current usage and remaining status of resources (such as server resources, virtual machine resources and container resources) to support cloud VR service operation; and provides real-time monitoring of the computing resources related to different computing nodes.

– Storage resource management: It provides monitoring functions for the usage of storage resources related to the current platform in a certain period.

– Data resource management: It provides functions of effective storage, resource allocation and distribution processing for the progress data strongly related to cloud VR contents and users.

– Running status monitoring: it monitors the occupancy of hardware resources such as CPU, GPU, memory and storage of each server, which lays the foundation for resource scheduling.

– Fault alarm monitoring: It monitors operating temperature, hardware faults, software alarms and other related information of each server.

13.6 Technology integration management

13.6.1 Cloud connectivity

Through the technology integration management function, the technology integration services on the cloud side can be accessed, deployed, updated and uninstalled.

– Technology integration access: It has a common interface to achieve various compliant cloud VR technology integration service certification and access, and provides cloud VR operation, CDN, cloud coding streaming, cloud rendering and other services.

– Technology integration deployment: For the cloud VR technology integration service that completes the access, the cloud-edge collaborative service deployment based on the cloud resource pool is realized, so that it can provide relevant cloud VR services to users.

– Technology integration update: After the relevant cloud VR technology integration service is deployed, it can support online version upgrades for the purpose of correcting errors and adding functional modules.

– Technology integration uninstall: When the relevant cloud VR technology integration service needs to be stopped, it is equipped to support its online uninstallation of related services in order to achieve the clearing of the corresponding function point.

13.6.2 Terminal binding

Through the technology integration management function, the technology integration service on the terminal side can be integrated, updated and uninstalled.

– Technology integration integrate: It has a common interface to realize various compliant cloud VR technology integration services integrated into the terminal side, and realize the functions of service request, service acquisition, service display and control feedback on the terminal side.

– Technology integration update: The cloud VR technology integration service for terminal docking needs to support online version upgrades for the purpose of correcting errors and adding functional modules.

– Technology integration uninstall: When the relevant cloud VR technology integration service needs to be stopped, it supports the uninstallation of services on the terminal side.

13.7 Network capability binds management

– Network authentication capability binding: It connects to the relevant authentication systems of network operators to obtain authentication permissions for network QOS services, network slicing services and network acceleration services.

– Network service interconnection: By stacking the capabilities of network operators, it has the ability to call QOS services, network slice services and network acceleration services end-to-end.

13.8 Terminal management

– Terminal binding: By obtaining the device information on the terminal side, the terminal is connected to the cloud VR system, and the cloud storage of information such as terminal model, operation capability, decoding capability, screen display capability and control capability is completed synchronously.

– Capability matching: Through unified terminal management, it completes the matching of relevant functions of cloud VR system and built-in network capabilities.

14 Functions of security for cloud virtual reality systems

14.1 Whole-process security

In the process of providing related services for cloud VR systems, it is necessary to provide end-to-end antivirus, process (logical) security assurance, security audit and other services for the whole process.

– End-to-end antivirus: In the end-to-end service process of cloud VR systems, it is necessary to establish and adopt antivirus mechanisms such as detection, protection, isolation, and removal to complete the protection or deletion of malware and malicious attacks.

– Process (logical) security assurance: For each functional module of cloud VR systems, a security guarantee mechanism is provided to isolate each other during logical processing to ensure that if one of the functional bodies has a problem with the operation, it can be isolated without affecting the service provision of other functions that they are not related to it.

– Security audit: Comprehensive analysis of system access permissions, service acquisition, service quality, and other related logs, combined with AI and other prediction methods, in order to obtain audit functions for discovering, predicting and timely handling related faults.

14.2 Content compliance

The content provided by the cloud VR systems needs to provide security mechanisms such as genuine protection, youth protection and fair use guarantees.

– Genuine protection: The cloud VR systems must provide legitimate authorized application content, and provide a copyright protection mechanism during the issuance and opening process, and prohibit illegal operations such as recompilation, data interception and tampering of application content.

– Youth protection: The application content provided by the cloud VR system needs to have a guarantee mechanism for the physical and mental health of youth, such as reminders of usage time, content suitability descriptions and anti-fraud reminders.

– Fair use mechanism: The application content provided by the cloud VR systems has the function of preventing other non-compliant tools to ensure fairness in the use of content.

– Content data security: For cloud VR content, establish an anti-tampering mechanism to prevent piracy and illegal changes to progress files. For the progress file corresponding to each content for the user, the backup mechanism is adopted to avoid damage or loss.

14.3 Service security

The cloud VR service system needs to provide mechanisms such as service access/call security, inter-user service security and service node security domain.

– Service access/call security: Only after service usage permission authentication can access/call permissions for various functional modules of cloud VR systems be obtained.

– Inter-user service security: The related functions of the cloud VR systems provide users with a relatively isolated service security mode, which user services between different service nodes and between different servers of the same node have security isolation attributes to avoid mutual interference and fault correlation.

– Service node security domain: For each service node related to the cloud VR systems, a domain specific security processing mechanism is adopted. Divide security domains according to service nodes, and deploy security measures such as firewalls, intrusion detection, abnormal traffic detection and filtering to ensure that faults within the security domain do not overflow and effectively isolate security issues outside the domain.

14.4 Data asset security

It provides effective encryption and other mechanisms to ensure the security of user privacy, metadata, operation data and content data security during cloud VR services.

– User privacy security: The cloud VR systems prohibit the collection and storage of user biometric data, encrypt personal privacy data such as user age, contact information and service usage, and prohibit non-compliant query and storage by operation and maintenance personnel.

– Metadata security: Ensure the stability of the metadata of the cloud VR systems, and have strict permission control for adding, modifying and deleting metadata, and provide a synchronization/update mechanism for the associated database/form during the metadata change process, as well as a rollback mechanism for the failed version.

– Operational data security: According to the industry or business sensitivity, establish a hierarchical processing mechanism for business operation data and the corresponding access level settings to ensure the security attributes of relevant operation data of cloud VR systems.

14.5 Cloud resource security

Cloud VR systems require cloud resource pools with software and hardware security guarantees, and deploy cloud VR services and call computing, rendering and storage capabilities through secure interactive interfaces.

14.6 Network security

In the process of network data transmission, relevant encryption processing is carried out to prevent packet splitting, tampering, network attacks and virus intrusion, and ensure that network capabilities call security, data integrity services and data confidentiality services.

– Network user authentication: Through the authentication and permission verification of identified entities (including users and devices) related to the network system, it can not only prevent unauthorized users from illegally accessing network resources, but also prevent legitimate users from accessing unauthorized users.

– Transmission data integrity service: In order to meet the data integrity requirements of different users and different occasions of the cloud VR systems, different data integrity functions are provided through relevant network transmission protocols and policies, such as connection-oriented data integrity with recovery function, connection-oriented data integrity without recovery function, data integrity facing the selection field connection, data integrity facing the selection field without connection, and data integrity without connection.

– Transmission data confidentiality services: In order to avoid passive threats such as information leakage and eavesdropping during network transmission, it is necessary to provide security protection and defence measures, such as encryption and other methods to protect information or data in network transmission.

14.7 User experience security

In order to prevent simulator sickness and ensure a safe user experience of cloud VR systems, it is necessary to make full use of the cloud-edge system mechanism to reduce the cloud and network processing latency during the computing and rendering process; based on AI and other mechanisms, predict the user's motion trajectory, and use pre-processing to reduce the delay of motion processing; improve the picture quality in the process of using the cloud VR systems through image enhancement processing; in view of the user experience problems that may be caused by long-term use, friendly reminders with a set duration are used to ensure the safety of the experience of the cloud VR system.

– Cloud-edge collaboration reduces latency: Multimedia resources in areas that are not currently of user's interest are delivered to edge nodes close to users in advance for timely processing during changes, reducing the response delay when FOV changes caused by user motion.

– Pre-processing reduces latency: By collecting and comprehensively processing the motion data of the user's desensitization when the FOV changes, based on the relevant information of the cloud VR terminal sensor, the direction, angle and distance of the motion are predicted in advance, and the cloud performs relevant multimedia processing in advance according to the prediction results, shortening the user's motion acquisition time and improving the timeliness of service.

– Enhanced processing to improve quality: In view of the problem that the multimedia quality of the current user's concern area may be insufficient during the change of user FOV, the AI mechanism can effectively improve the user's experience quality.

– Effective reminder of usage time: When users use the cloud VR system to reach the duration period that affects health or experience quality, provide corresponding friendly reminders, and recommend users to take a break.

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