Cloud VR

Solution White Paper

HUAWEI

Preface

Cloud VR is one of the main application scenarios of Gigabit home broadband and a typical application of 5G. Cloud VR presents a new business opportunity for operators: Not only can it convert a large number of video users to VR users, but also their networks will need to be upgraded as a result, increasing ARPU for operators.

Huawei released the VR OpenLab industry cooperation plan at the Ultra-Broadband Forum in October 2017, calling for VR industry partners to jointly explore business scenarios, make technological innovations, incubate solutions, and achieve commercial deployment of Cloud VR. After working together for nearly a year, Huawei and its industry partners have completed the Cloud VR solution. On July 18, 2018, the Cloud VR solution officially took shape when China Mobile Fujian launched the first commercial Cloud VR service in the world.

Jointly written by Huawei, Letin VR, Cyber Cloud, Pico, and DPVR, this white paper can be used as a reference for operators and VR industry partners who want to develop Cloud VR services. We also hope that more operators and VR industry partners will join in to promote the development of the Cloud VR industry.

Contents

01 The Advent of the Cloud VR Era

Cloud Virtual Reality (Cloud VR) incorporates cloud computing and cloud rendering into VR services. With fast and stable networks, cloud-based display output and audio output are coded, compressed, and transmitted to user terminals, implementing cloud-based VR service content and content rendering.

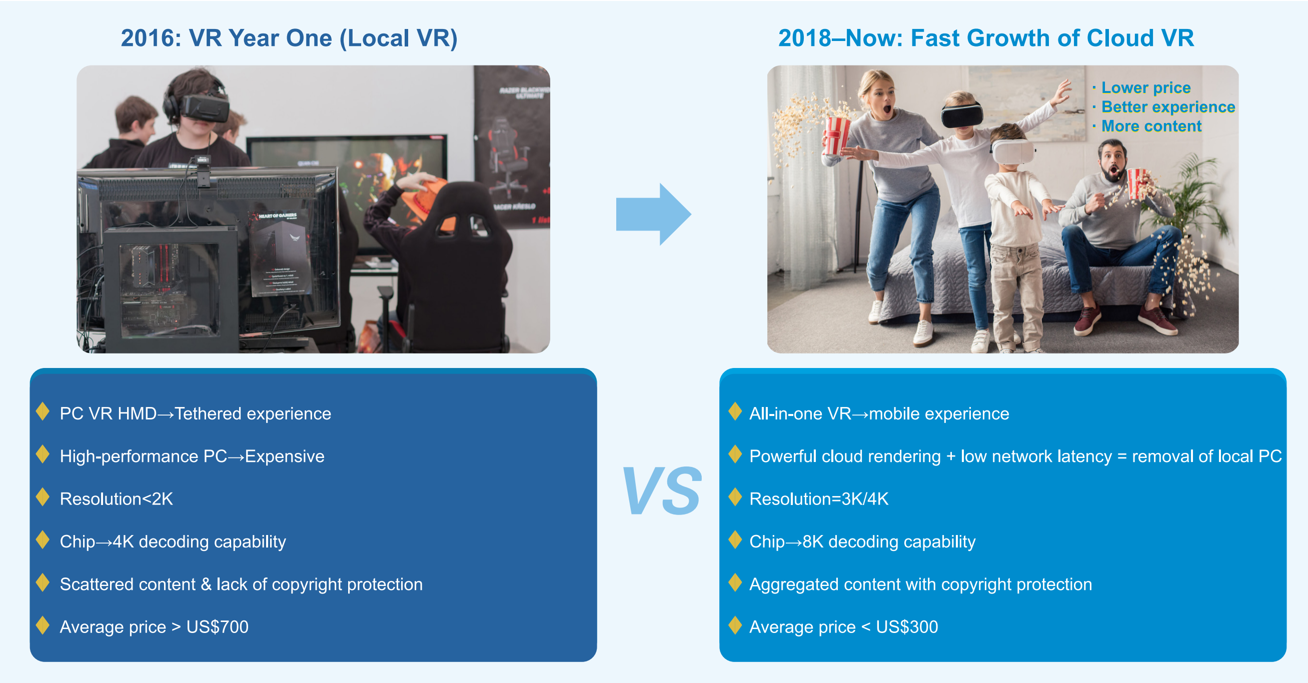

Figure 1-1 Cloud VR value

Thanks to the emergence of VR terminals, service platform solutions, and an increasingly wide variety of content, the Cloud VR industry has become mature. This transition has been marked by some operators releasing Cloud VR services and some home users subscribing to Cloud VR services.

1.1 Cloud VR Services Released by Telecom Operators: Historic Moments for VR

1.1.1 China Mobile Fujian (Fujian Mobile): Five Types of Cloud VR Applications for Users

In July 2018, Fujian Mobile launched its commercial Cloud VR services, including VR onsite, VR broadcast, VR IMAX, VR gaming, and VR education services.

Figure 1-2 Launcher of the Cloud VR services of Fujian Mobile

Image source: https://mp.weixin.qq.com/s/8aD0b_O6slgZNnAKHUk8Sw

The Cloud VR services use the computing power provided by the cloud GPU rendering and cloud server architecture to ensure stable transmission of VR video streams and high-resolution image display. This reduces requirements on required hardware computing capability of VR terminals, makes it possible to simplify VR terminal hardware, and makes VR services more affordable. Users can experience VR services at home through their Gigabit fiber broadband and intelligent home networks.

1.1.2 KT Corp (Korea): VR Theme Park VRIGHT

KT Corp, the largest telecom company in Korea, announced the launch of the VRIGHT VR theme park jointly with GS Retail in July 2018. VRIGHT uses 5G networks and the latest VR information communications technologies. Enhanced by the offline retail operation and distribution experience of GS Retail, VRIGHT provides users with more than 30 new immersive games. KT Corp also plans to launch personal VR cinema services and increase the number of VR theme parks to 200 by 2020.

1.2 The Growing Appeal of Cloud VR Services

From January to July 2018, Cloud VR services have been experienced by over 10,000 people from all age groups and scenarios, including Cloud VR games, live broadcasting, VR 360° video, education, and IMAX.

User feedback shows that users are satisfied with the experience of Cloud VR. Many users have said that the experience is almost the same as the experience provided by local VR services.

At a recent summit, nearly 4500 people experienced Cloud VR, and it made a big impression: Approximately 22% of these people asked how to subscribe to the services.

1.3 A Variety of Business Scenarios and Huge Market Worth

According to the *Worldwide Semiannual Augmented and Virtual Reality Spending Guide* released by IDC in November 2017, the VR market is expected to be worth $174 billion in the next five years (by 2023).

Cloud VR has a larger user base, content aggregation platforms, and content copyright protection. It is easier to aggregate content and deploy services on a large scale with Cloud VR than with local VR.

Huawei VR OpenLab has identified the Cloud VR scenarios that have the most commercial potential and are expected to gain popularity first. Services in these application scenarios are further classified as having strong or weak interaction.

Weak-interaction VR services mainly comprise VR video services, including IMAX theater, VR 360 ° panoramic video, and VR live broadcast. Users can select the view and location, but they cannot interact with (for example, touch) entities in the virtual environment.

Strong-interaction VR services include VR games, VR education, VR home fitness, and VR social networking. In these scenarios, users can interact with virtual environments through interactive devices. The virtual space displayed needs to respond to interactions in real time.

Figure 1-3 Cloud VR scenarios

1.4 Resolving VR Pain Points and Preparing Cloud VR for Commercial Use

In 2017, Huawei VR OpenLab identified 10 pain points of Cloud VR services in terminals, networks, business strategies, platform construction strategies, and user experience. Most of the pain points have all been resolved or alleviated through continuous technological innovation in the industry.

1. Various types of all-in-one devices that offer improved definition and comfort are selling very well.

- **Top-selling all-in-one devices are emerging**
  In August 2018, an HMD manufacturer in China released the first 8K VR video hardware decoding device.

- **Various types of all-in-one devices are available**
  Qualcomm mentioned that more than 40 all-in-one VR products in the global market use Snapdragon 835 chips. Among them, more than 20 products have become available on the market, and more than 20 products are under development.

- **The resolution of all-in-one devices keeps increasing**
  Terminal resolution determines user experience. Most all-in-one devices on the market provide 3K or 4K resolution (for both eyes). When the resolution is 2K, minor screen-door effect occurs. When the resolution is 3K, the screen-door effect is further alleviated. When the resolution is 4K, the screen-door effect is almost eliminated.

- **HMDs are more comfortable to wear**
  The weight of VR terminals is more evenly distributed. VR terminals are no longer front-heavy, and some HMDs even provide blue light protection, making VR terminals significantly more comfortable to wear.

2. Networks provide high bandwidth and low latency for Cloud VR services

- **Gigabit broadband provides a high bandwidth for Cloud VR services.**
  To meet concurrent traffic requirements in multi-screen scenarios, bandwidth must exceed 100 Mbit/s. For example, if VR video/VR gaming, Internet access, and screen projection are used at the same time, Gigabit broadband is required. In 2018, the Ministry of Industry and Information Technology (MIIT) of China released the *2017 Communications Industry Statistics Bulletin*, in which it was reported that the fixed network Internet bandwidth of 135 million users in China has reached 100 Mbit/s or higher. The MIIT and the State-owned Assets Supervision and Administration Commission of the State Council (SASAC) are promoting the deployment of high-capacity optical fibers. Gigabit broadband services are now provided in over 100 cities.

- **High-performance 5G Wi-Fi provides low latency for Cloud VR services.**
  The requirements of VR video services on home Wi-Fi networks are not so different from those of traditional video services. However, strong-interaction VR services place great demands on Wi-Fi bandwidth and latency. The 5 GHz frequency bands can meet these requirements.

3. Cloud VR business development and platform construction strategies are clear.

Cloud VR services have just started, making it a very opportune time for service development. The development of Cloud VR services can be divided into two phases.

- **Phase 1: Launch VR scenarios that are more likely to gain popularity and quickly develop the B2H Cloud VR market.**

Based on existing video platforms, VR IMAX, VR live broadcast (by Internet celebrities), and VR 360 ° video. Such content is abundant and appealing, and can be used to convert common video users to VR users. When the number of users grows to a certain level, user loyalty can be achieved by purchasing copyrighted content, such as concerts and sports events, making profits from paid users.

VR games and VR education are a necessity. New Cloud VR platforms can be built to support VR gaming and VR education scenarios. The immersive experience can generate user spending and in turn, profits.

- **Phase 2: Expand the Cloud VR platform and develop the Cloud VR B2B market.**
  Operators can leverage their cloud rendering capabilities and strengths in premium broadband to provide cloud rendering and content storage resources for applications, such as VR education, eSports, VR shopping, and VR healthcare in B2B market.

4. The Cloud VR experience is better than the local VR experience.

MTP ≤ 20 ms is a critical requirement for good VR experience. VR cloudification introduces new latency sources, making it challenging to keep MTP within 20 ms. However, existing technologies can ensure that the MTP is within 20 ms, and many users have said that Cloud VR provides better experience than local VR.

- **Similar sense of realism**
  Cloud VR and local VR have the same indicators that affect users' sense of realism when using Cloud VR. The indicators include resolution, color depth, frame rate, encoding compression technology, and FOV.

- **Superior sense of interactivity**
  A user's sense of interactivity depends on interaction freedom, MTP, and interactive latency. Cloud VR offers greater freedom than local VR because no cords are involved. Users can move and interact with each other freely. The MTP of Cloud VR does not exceed 20 ms. Therefore, Cloud VR will not increase dizziness. Cloud VR and local VR comply with the same interaction latency standard, which is ITU-T G.114. Therefore, the perceived delay is similar.

- **Similar sense of enjoyment**
  A user's sense of enjoyment is compromised by frame freezing and artifacts, for which networks are responsible. The latency of Cloud VR networks is similar to that of local VR.

02
Cloud VR Solution

2.1 Cloud VR Solution Overview

2.1.1 Cloud VR Solution Architecture

The Cloud VR solution consists of a content layer, platform layer, network layer, and terminal layer.

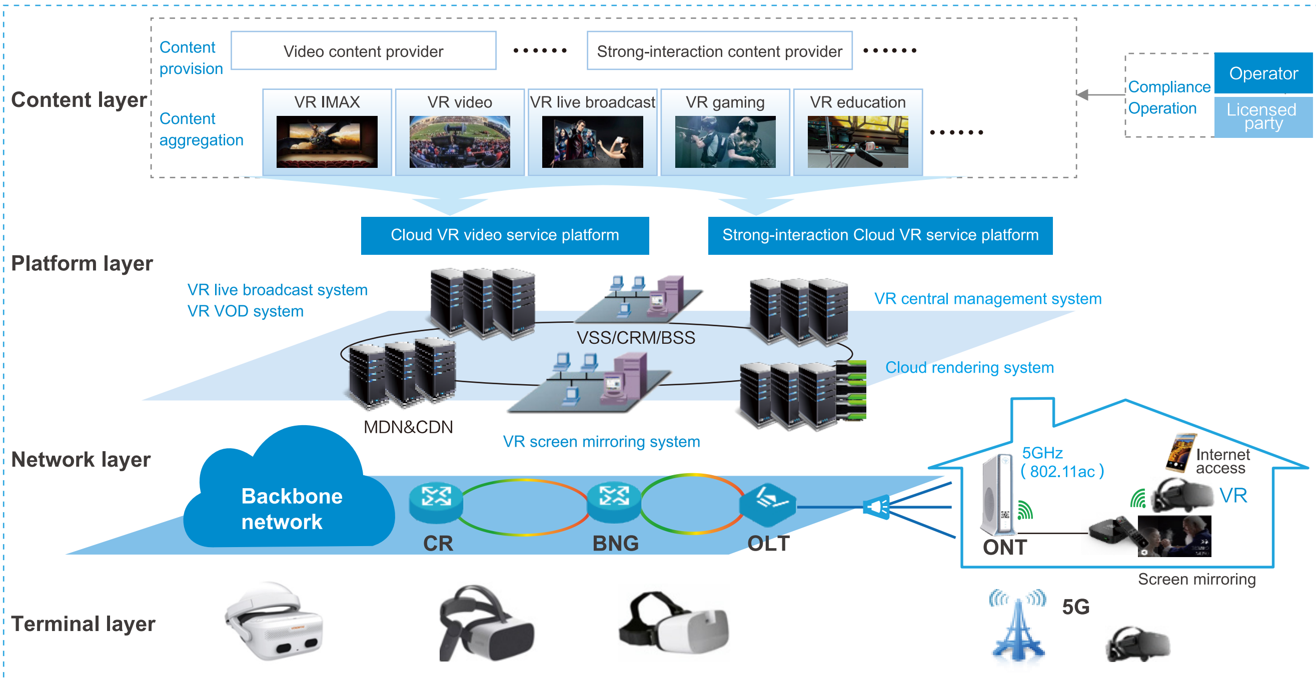

Figure 2-1 Cloud VR solution architecture

1. Content layer

At the content layer, content providers and aggregators provide VR content to the platform layer. This content includes Cloud VR video services and strong-interaction services.

2. Platform layer

The platform layer provides functions such as cloud rendering, streaming, transcoding, storage, and encoding for Cloud VR video services and strong-interaction Cloud VR services.

- **Cloud VR video service platform**

  The Cloud VR video service platform consists of the VR VOD system, VR live broadcast system, media distribution system (MDN), and content delivery network (CDN). The platform implements VR video import, transcoding, storage, broadcast control, and distribution. Unlike mature IPTV and OTT video service platforms, the Cloud VR video service platform should support panoramic video data transmission and future field of view (FOV) transmission.

- **Strong-interaction Cloud VR service platform**

  The platform renders strong-interaction services, including instance running, logic computing, real-time rendering, and real-time streaming. It generates an application instance for each user on the cloud and renders, encodes, and streams VR content in real time.

- **VR screen mirroring system**

  The VR screen mirroring system provides a reliable synchronization mechanism for exchanging messages between a VR headset and STB. In this way, VR content can be synchronously displayed on home TV screens, allowing users to share their VR world with family and friends.

3. Network layer

The network layer consists of the backbone network, metro network, access network, and home network. It provides stable transmission with high bandwidth and low latency.

4. Terminal layer

A Cloud VR terminal implements functions such as VR content presentation, home network access, and user authentication. It accesses the network and platform layer over Wi-Fi.

2.1.2 Key Constraints of the Cloud VR Solution

Latency is a key constraint of the entire solution. Compared with local VR, the Cloud VR system has a longer latency, which may cause motion sickness if not properly controlled.

Motion sickness is caused by inconsistency between the user vision and the motion state sensed by the foreground system. Symptoms include nausea, pale skin, cold sweat, vomiting, dizziness, headache, fatigue, and others. There are two broad causes of motion sickness in VR scenarios. The first is the lag of the display picture after a motion (changing one's head position and viewing angle). The second is that the images are moving, but the user is not. Currently, the industry predominantly agrees that the latency of the motion to photon (MTP) of a VR device should not exceed 20 ms. If the latency between the motion of the human head and the image changes displayed is less than 20 ms, users are unlikely to experience motion sickness.

Cloud VR video services have lower requirements on latency. Based on the 4K video analysis result, differences in latency only affect the image loading time. For strong-interaction Cloud VR services, additional latency is introduced during cloud rendering, often pushing MTP beyond 20 ms. If the latency is not properly controlled, motion sickness is more likely to occur. To make Cloud VR experience consistent with local VR experience, the Cloud VR solution needs to control the latency to meet the MTP latency requirement of less than 20 ms.

2.1.3 Service Experience Indicators of the Cloud VR Solution

The service experience indicators of the Cloud VR solution can be determined by referring to the local VR service experience requirements. The following indicators must be met:

Service Type	Service Indicator	Indicator Requirements
Terminal	Terminal resolution	2K–4K
Strong-interaction Cloud VR services	Content resolution(equivalent full-view resolution)	2K–4K(equivalent full-view: 4K–8K)
	Color depth (bits)	8
	Coding mode	H.264/H.265
	Bitrate (Mbit/s)	≥40
	Frame rate (FPS)	50–90
	FOV (degrees)	90–110
	Interactive latency (ms)	≤100
	MTP (ms)	≤20
	Valid frame rate	100%(note)
Cloud VR video services	Content full-view resolution	4K–8K
	Color depth (bits)	8
	Coding Mode	H.264/H.265
	Bitrate (Mbit/s)	≥40
	Frame rate (FPS)	30
	FOV (degrees)	90–110
	Interactive latency (ms)	≤100
	Initial buffer latency (s)	≤1
	Stalling duration ratio	0
	Pixelization duration ratio	0

Table 2-1 Service experience indicators of the Cloud VR solution

Note: When the network transmission quality deteriorates, the frame data cannot reach a terminal and be decoded by the terminal within the specified time. As a result, the images become discontinuous or jitter. A valid frame rate of 100%indicates that the rate of frames actually received and decoded by a terminal from the cloud is not lower than the required frame rate.

2.2 Strong-interaction Cloud VR Services

Strong-interaction Cloud VR services allow users to interact with cloud applications in real time. The cloud responds to interaction behaviors, and performs computing, rendering, encoding, and compression in real time, and then transmits the video stream to be displayed on terminals. Cloud VR games are typical examples. If the live network does not have a Cloud VR platform, a new service platform on which to run and render VR applications must be built. The 4K Ready network can be adjusted to meet bandwidth and latency requirements of VR services.

2.2.1 Overall Design of the Strong-interaction Cloud VR Service Solution

2.2.1.1 Solution Composition

The strong-interaction Cloud VR service solution consists of three parts: Strong-interaction Cloud VR service platform, network, and Cloud VR terminal.

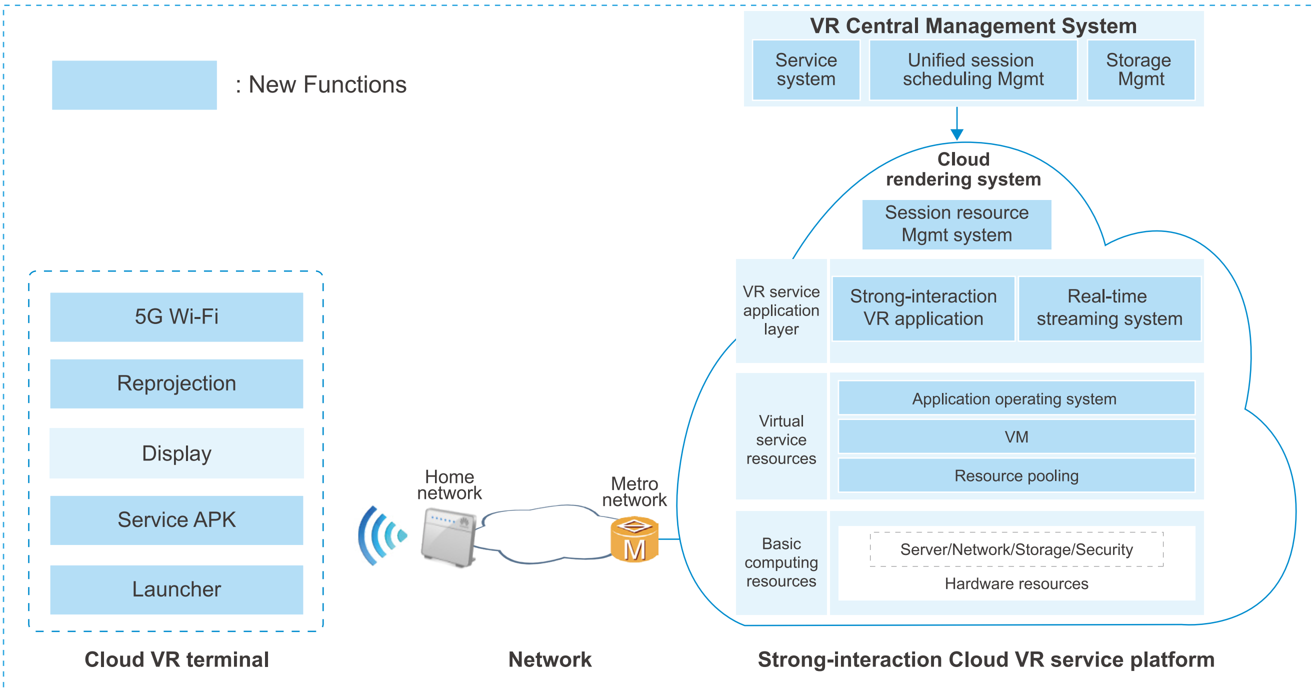

Figure 2-2 Strong-interaction Cloud VR service solution

1. Newly-built strong-interaction Cloud VR service platform

The service platform consists of a central management system and cloud rendering system. It manages, stores, and renders strong-interaction Cloud VR services. Cloud rendering includes logical computing, real-time rendering, encoding, and streaming.

2. Network

To cost-effectively deploy Cloud VR services, operators can adjust the 4K ready bearer network architecture to meet Cloud VR bandwidth and latency requirements. Operators can construct a Wi-Fi home network which terminals access to receive Cloud VR services. The key is to deploy high-performance Wi-Fi APs.

3. Cloud VR terminals

Cloud VR terminals mainly refer to all-in-one VR devices which control the collection of controlling signals, video decoding, screen presentation, and network access. Unlike local VR terminals, Cloud VR terminals provide a startup screen, launcher screen, and user authentication, and need to support a 5G Wi-Fi communication module to access the network through Wi-Fi, connect to the service platform, and access the VR applications.

2.2.1.2 Keeping MTP Within 20 ms for the Cloud VR Solution

As already mentioned, strong-interaction Cloud VR service systems have longer latency, which may intensify motion sickness if not properly controlled. The solution must ensure that MTP does not exceed 20 ms to avoid motion sickness, and the system latency and image quality must be strictly controlled. This solution uses asynchronous terminal-cloud rendering to control the system latency of strong-interaction Cloud VR services.

1. Asynchronous terminal-cloud rendering allows Cloud VR MTP ≤ 20 ms

Cloud VR processing includes cloud rendering and streaming and terminal display. During cloud rendering and streaming, a Cloud VR terminal captures actions and transmits the information over the network to the cloud. The cloud performs logic computing, real-time rendering, encoding, compression, and then transmits the video stream to the terminal for decoding, as shown in the following figure:

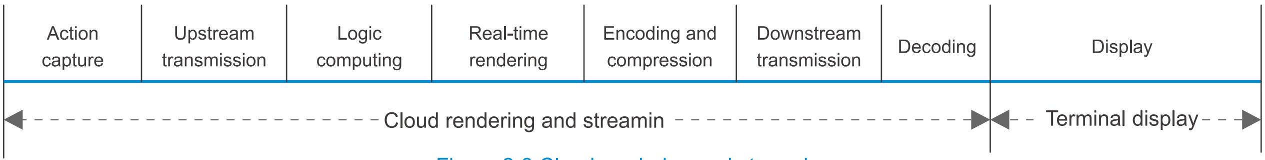

Figure 2-3 Cloud rendering and streaming

It is already difficult for a local VR terminal to meet MTP latency requirements when performing action capture, logic computing, image rendering, and screen display. It is more challenging for Cloud VR to meet these requirements. If cloud rendering and streaming and terminal display are performed in serial mode, it is nearly impossible to keep MTP below 20 ms. The key problem is that network transmission, encoding, and decoding are introduced during cloud rendering and streaming, increasing MTP latency, as shown in the following figure.

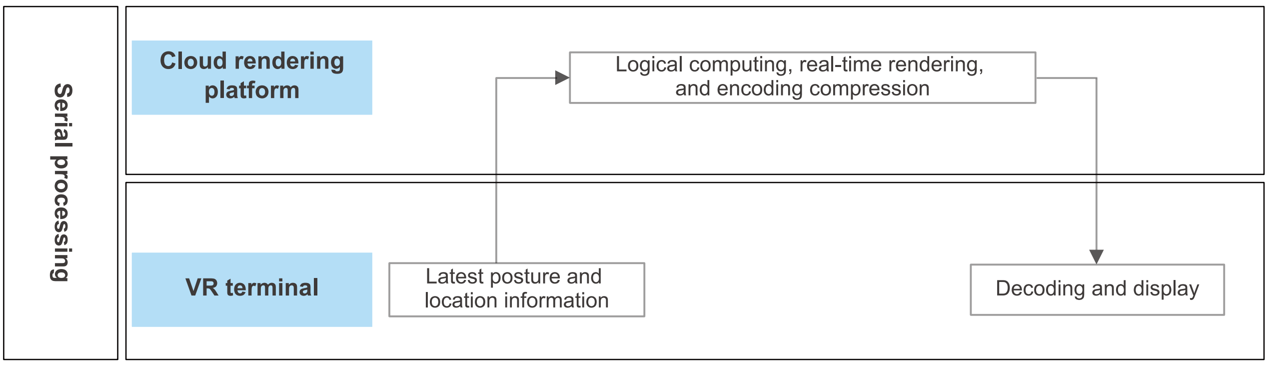

Figure 2-4 Solution which cannot guarantee the MTP

A fundamental tenet of asynchronous terminal-cloud rendering is that the cloud rendering and streaming process and terminal refreshing process for display should occur in parallel instead of serial mode. That is, each time a VR terminal refreshes the image, the n frame sent by the cloud rendering platform is used as the basic frame for reprojection. Meanwhile, the cloud rendering platform renders the n+1 frame in parallel mode, as shown in the following figure. In this case, the MTP is determined by the terminal and does not depend on network or cloud rendering; therefore, the MTP can be kept below 20 ms.

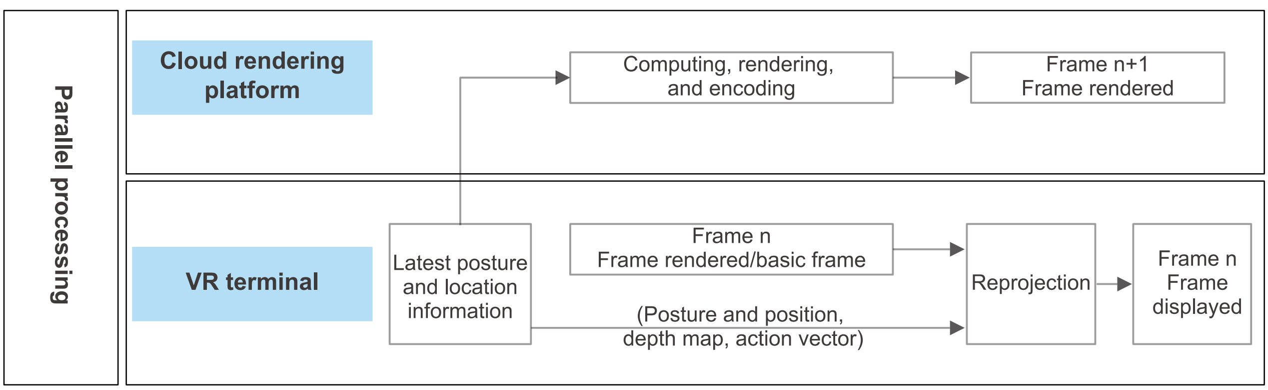

Figure 2-5 Solution to guarantee MTP–asynchronous terminal-cloud rendering

Note：Reprojection refers to predicting and adjusting a current image based on the changes in the posture and location information.

2. Limit cloud rendering and streaming latency to less than 70 ms, reducing black edges and improving image quality

Although cloud rendering and streaming latency do not affect the MTP, the latency still affects the image quality and user experience. If the cloud rendering and streaming latency is unrestricted, the following problems may occur:

- **Black edge problem**

  Asynchronous terminal-cloud rendering expands the rendering image by using ultra FOV rendering to reduce the black edges caused by the reprojection of the FOV images (as shown in the following figures). The larger the latency between cloud rendering and streaming, the larger the images that should be rendered. However, rendering larger images requires more cloud resources. In general, the angle of images to be rendered will not be increased significantly. If cloud rendering and streaming latency is too large, black edges may persist, affecting user experience.

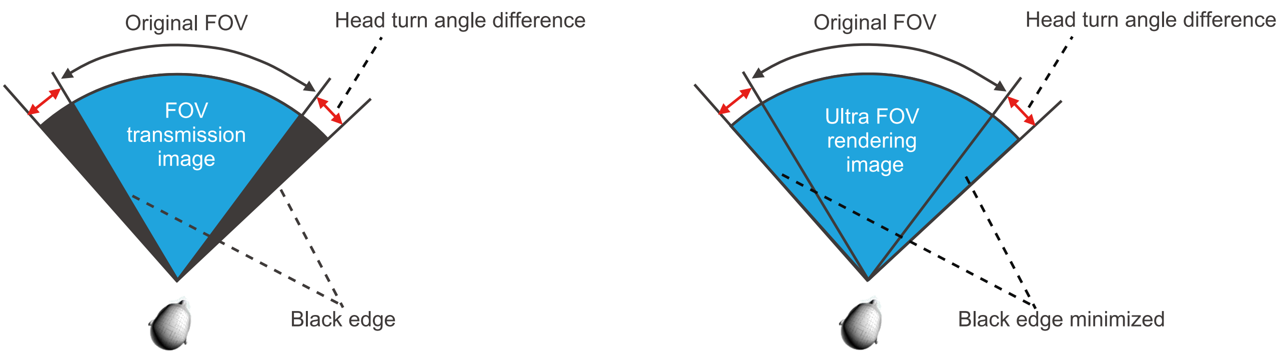

Figure 2-6 Black edge problem and optimization method

- **Image quality problems**

  Asynchronous terminal-cloud rendering uses reprojection to adjust the overlapping between image objects. The overlapping part is usually replaced by surrounding images, which may distort images. If the cloud rendering and streaming latency is too large, the image distortion will be obvious and user experience will be affected.

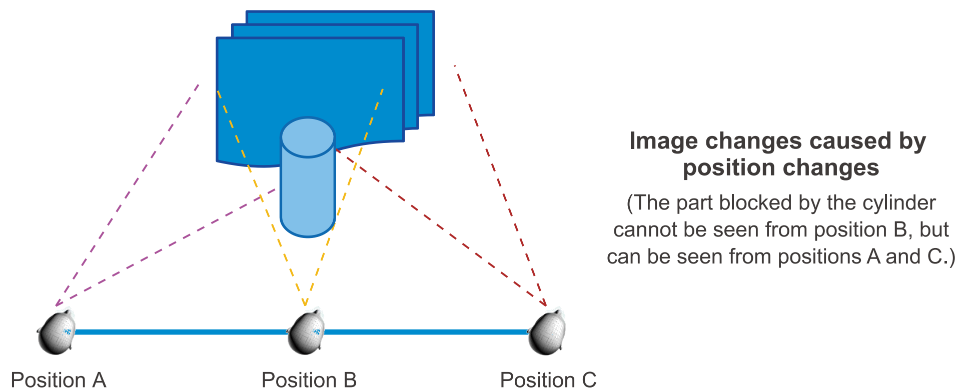

Figure 2-7 Image overlapping relationships

Therefore, the cloud rendering and streaming latency must be restricted to ensure Cloud VR user experience. According industry test results, cloud rendering and streaming latency should be below 70 ms.

2.2.1.3 Key Indicators for Cloud VR Strong Interaction

To keep cloud rendering and streaming latency below 70 ms, the solution needs to distribute the latency among the cloud, pipe, and device (as shown in Figure 2–3) in three parts: cloud processing, network transmission, and terminal decoding and synchronization.

- **Cloud processing latency**

  Cloud processing includes logical computing, content rendering, encoding, and data transmission. VR industry partners suggest that the latency caused by parallel processing of logical computing, content rendering, and encoding should be about 10–15 ms, and the data transmission latency should be about 10–15 ms. That is, the total latency for cloud processing should be below 30 ms.

- **Network transmission latency**

  Based on project practice data and subjective experience tests on multiple lab study participants, if the network transmission latency is larger than 19 ms, hysteresis is slightly perceptible; if the latency is larger than 23 ms, the head turning experience deteriorates, and obvious black edges occur. In summary, the network transmission latency should be below 20 ms.

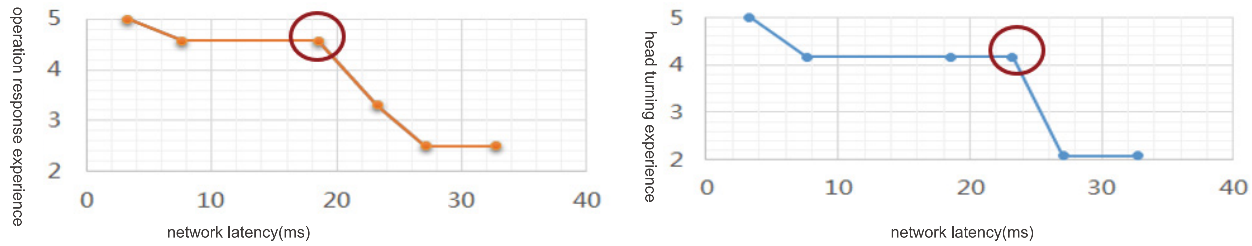

Figure 2-8 Impact of network transmission latency on interaction and head turning experience

- **Terminal decoding and synchronization latency**

  If the decoding capability of a VR terminal is 90 frames per second (FPS), the decoding latency is about 11 ms. The asynchronous time between the cloud platform and terminals is generally 0–1 cycles. Therefore, the decoding and synchronization latency should be below 20 ms.

  The following figure shows the E2E latency of strong-interaction Cloud VR services.

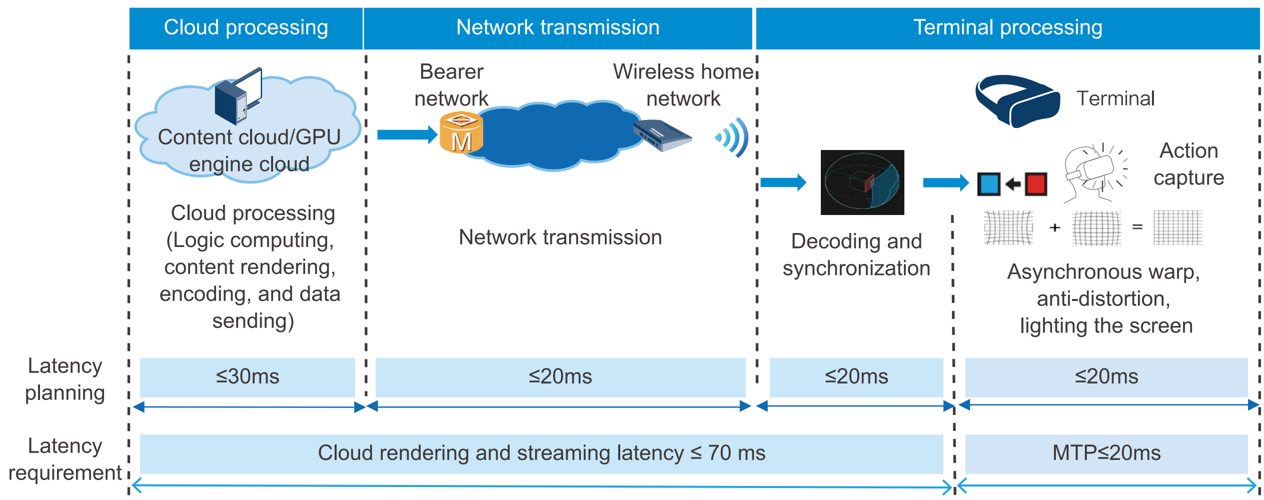

Figure 2-9 Latency of strong-interaction Cloud VR services

2.2.2 Planning and Deploying the Strong-interaction Cloud VR Service Platform

When planning and deploying a strong-interaction Cloud VR service platform, ensure that cloud processing latency is less than 30 ms. The data center location, server hardware performance, and GPU/CPU resource performance all contribute to this requirement.

2.2.2.1 Strong-interaction Cloud VR Service Platform Planning

The platform consists of the VR central management system and cloud rendering systems. The VR central management system can manage multiple cloud rendering systems simultaneously.

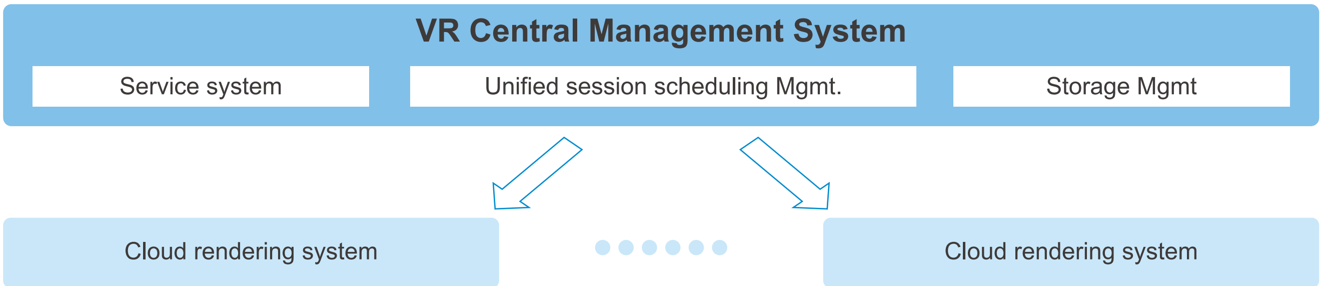

Figure 2-10 Relationship between the VR central management system and cloud rendering systems

1. VR central management system

Consists of the service system, unified session scheduling management module, and storage management module.

- The service system manages users and applications, and provides service operation interfaces for users.
- The unified session scheduling management module processes user login requests, selects proper cloud rendering systems for users, and centrally schedules, allocates, and manages user sessions and running instances in each cloud rendering system.
- The storage management module stores user data.

2. Cloud rendering system

The cloud rendering system is a core component of the service platform, and processes the logical computing, real-time rendering, encoding, and streaming for VR applications. The cloud processing latency of less than 30 ms needs to be guaranteed by the cloud rendering system.

A cloud rendering system can be either a non-common or common cloud rendering solution.

- **Non-common cloud rendering solution, making strong-interaction Cloud VR services quickly available**

The non-common solution uses physical servers to construct virtual machines (VMs), and uses virtualization technologies to support multiple VR services. For example, four virtual machines can be deployed on one server. Each virtual machine has an operating system and runs an isolated instance, supporting four users on one server. This solution is mature and can be used to quickly provision strong-interaction services.

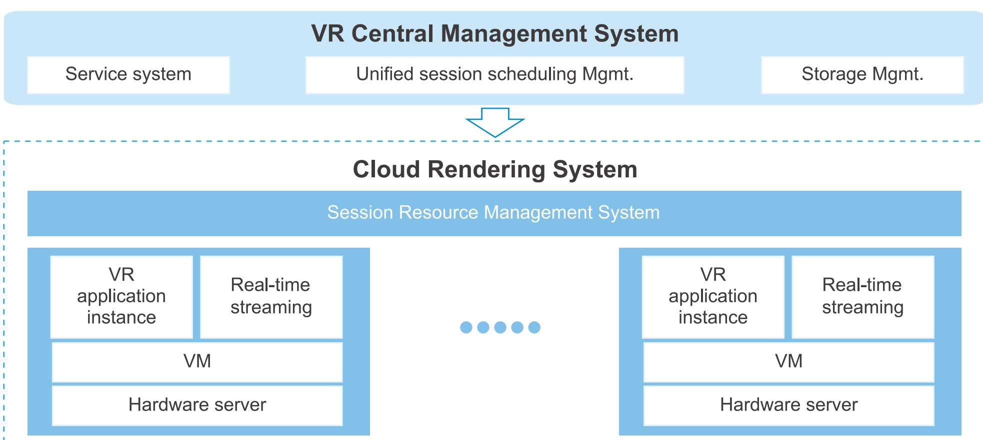

Figure 2-11 Non-common solution for cloud rendering

- **Common solution for cloud rendering, applicable to large-scale cost-effective commercial use**

In the common cloud rendering solution, hardware resources are pooled to form CPU computing, GPU rendering, and storage resource pools. Then, multiple VMs are constructed as the running environments for VR services. CPU computing resources and GPU rendering resources of VMs can be dynamically allocated. This allows GPU resources to be elastically scaled on demand, improving resource utilization. This solution is suitable for deploying a cloud rendering platform for not only consumer VR applications but also 2B industry applications.

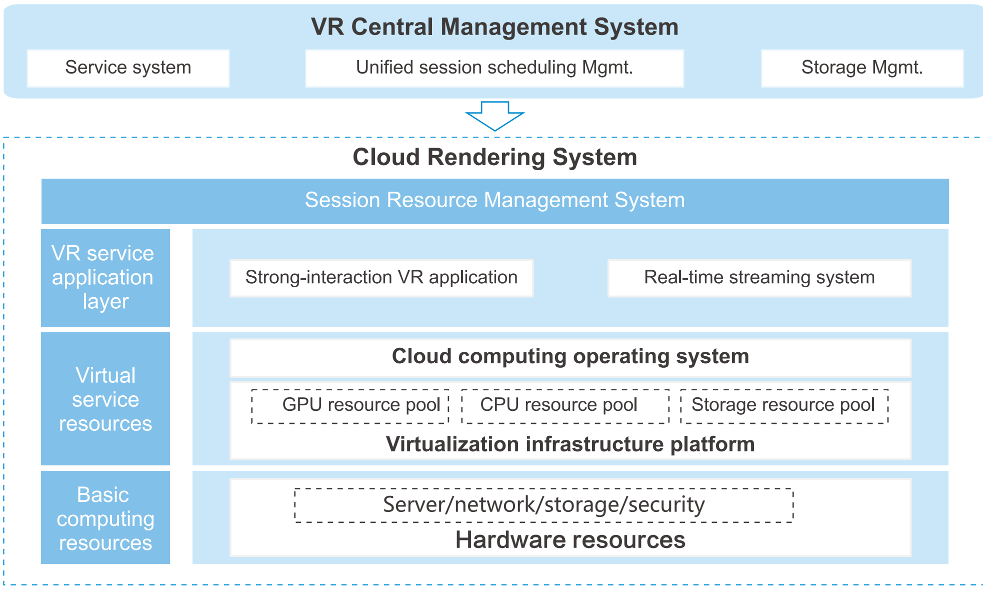

Figure 2-12 Common solution for cloud rendering

The common cloud rendering solution consists of basic computing resources, virtual service resources, and the VR service application layer. It is generally deployed at data centers close to users.

- **Basic computing resources**

Refers to physical computing resources, such as servers, networks, and storage, which can be virtualized as logical resources to meet requirements of the upper virtual service layer.

- **Virtual service resources**

Provides shared GPU, CPU, and VM resources required for VR service computing, rendering, and storage. It also provides the operating system environment required for running VR service application instances.

- **VR application service layer**

Provides various VR application running environments. The session resource management system implements communication between VR terminals and the cloud, and maintains the user access lifecycle. A strong-interaction Cloud VR application module provides a VR application instance for each user and performs computing and rendering. The real-time streaming system pushes video streams to users.

2.2.2.2 Strong-interaction Cloud VR Service Platform Deployment

Basic Computing Resource Deployment

1. Deployment location

The strong-interaction Cloud VR service platform has distributed system architecture. It is recommended that the server of the central management system be deployed in the central cloud, such as a provincial central equipment room. Servers of the cloud rendering system are recommended to be deployed in city equipment rooms near users, such as on the regional cloud or edge cloud to reduce transmission latency and ensure user experience.

As the number of users keeps increasing, deploy more or new cloud rendering system servers close to users as necessary.

2. Hardware resource planning

- **VR central management system**
  Requires servers with at least quad-core CPUs with a dominant frequency of 2.1 GHz or higher and 8 GB memory.

- **Cloud rendering system**
  Depends on the user scale and the concurrency rate of strong-interaction services. The required hardware must be evaluated in advance, which directly affects the deployment of servers and quantity of spare parts. The following example uses the application scale of 2000 users:

  Hardware requirement: Servers with at least 22-core CPUs with a dominant frequency of 2.6 GHz, 60 GB memory, 10 GE network adapters, and high-performance graphics cards such as NVIDIA M60. One NVIDIA M60 graphics card supports concurrent rendering for eight users. Assuming that the concurrency rate is 5%, at least 13 graphics cards are required for 2000 users. If two graphics cards can be configured on one server, at least 7 servers are required.

Virtual Service Resource Deployment

1. VM deployment

Hardware resources such as servers need to be virtualized. To do so, a virtualization system, such as FusionSphere, needs to be deployed.

2. Operating system deployment for application running

Generally, the VR central management system and cloud rendering system can run on common operating systems, such as Windows.

VR Application Service Deployment

1. Deploy the VR central management system modules, such as central session resource management and storage management modules.

2. Deploy the cloud rendering system modules, such as the VR strong-interaction application module and streaming systems. The VR strong-interaction module performs logical computing and real-time rendering for applications. The parameter settings (including resolution and frame rate) for a cloud rendering system affect VR experience.

- **The resolution setting must meet the rendering requirement of ultra FOV images. The pixel points of the rendered images are calculated as follows:**

Pixel points of rendered images=

$$\text{Headset single eye resolution} * \left(1 + \frac{\text{Asynchronous distortion ultra FOV rendering angle}}{\text{FOV}}\right)^2 * (1+\text{FOV extra image})^2$$

The recommended rendering angle for asynchronous warp ultra FOV is 12 degrees (6 degrees in each direction). FOV extra images refer to a 10% increase in the horizontal and vertical directions. The FOV is the FOV of the terminal.

- **Frame rate**

  Considering the processing capability of current cloud platforms, the frame rate can be set to 50 FPS for strong-interaction services and gradually increased to 90FPS as capabilities improve.

3. VR application deployment

There are a variety of VR strong-interaction service applications. Typical applications include games and highly professional applications such as medical care. Services can be developed to support action and control, puzzle, single-person shooting, and man-machine interaction games first. These services have lower requirements on control precision and are suitable for home users. In the future, large-scale games such as robotics, multi-person interaction, and strong interaction games can be developed. These games have high requirements on image quality, operation, and interaction precision, as well as higher cloud rendering capabilities.

Applications such as VR games must be installed in the deployed VR strong-interaction application module, and need to be configured in order to run properly.

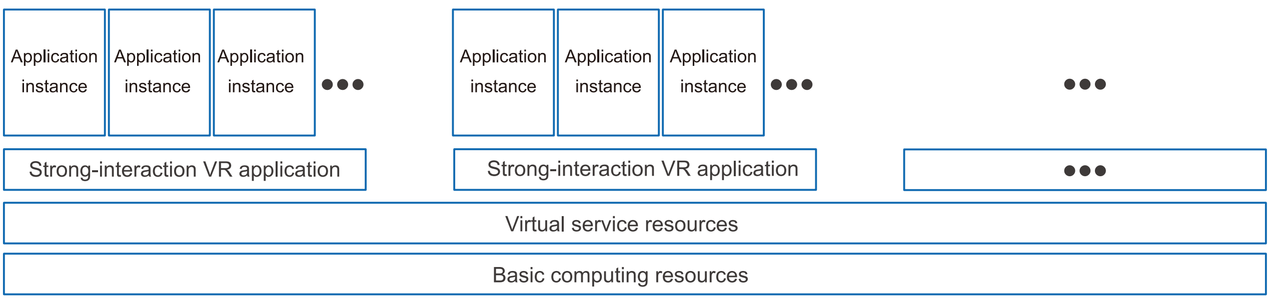

Figure 2-13 Deploying VR applications

Image Quality Between the Service Platform and Cloud VR Terminals

For a Cloud VR terminal to access the strong-interaction Cloud VR service platform and use the applications on it, interconnection must be customized on both ends to implement functions such as user login and authentication, application startup or stop, control signaling interaction, and video streaming.

Interconnection Between the Service Platform and STB

Screen mirroring is a rigid requirement for VR services. The strong-interaction Cloud VR service platform needs to be interconnected with STB terminals. The cloud rendering system needs to stream video to STBs for displaying upon receiving requests from STB terminals.

2.2.3 Planning and Deploying the Strong-interaction Cloud VR Service Network

2.2.3.1 Network Requirements for Strong-interaction Cloud VR Services

Network KPI Requirements

Service Scenario	Indicator	Reference Value
Strong-interaction VR service	Bandwidth	≥80Mbit/s
	Round trip time (RTT)	≤20ms
	Packet loss rate	1.00^{-5}
Multi-service concurrency	Internet access, VR strong interaction services, and screen mirroring	260Mbit/s

Table 2-2 Network KPI requirements for strong-interaction Cloud VR services

Note：During network planning and deployment, multiple services can coexist in the home scenario, and the requirement for the home bandwidth can reach 260 Mbit/s. For example, the bandwidth requirements are 80 Mbit/s, 80 Mbit/s, and 100 Mbit/s for a single channel strong-interaction VR service, 4K IPTV service (including screen mirroring, and can be reduced to 50 Mbit/s with head-end screen mirroring service compression), and Internet access, respectively, totaling 260 Mbit/s.

Network KPI Requirements

The network round trip time (RTT) must be below 20 ms, comprising the following segments:

E2E RTT	Home Wi-Fi	Fixed Access Network	Metro Bearer
≤20 ms	≤10 ms	≤2 ms	≤8 ms

Table 2-3 Network latency requirements for strong-interaction Cloud VR services

For details about the network solution, see the Cloud VR Network Solution White Paper.

2.2.3.2 Cloud VR Network Architecture

Currently, the Cloud VR network construction strategy is to partially reconstruct the existing network to quickly and cost-effectively deploy Cloud VR services. The following figure shows the core method underlying the Cloud VR network solution, which is Wi-Fi home network + 4K ready bearer network + reusing the CDN/adding new cloud rendering servers.

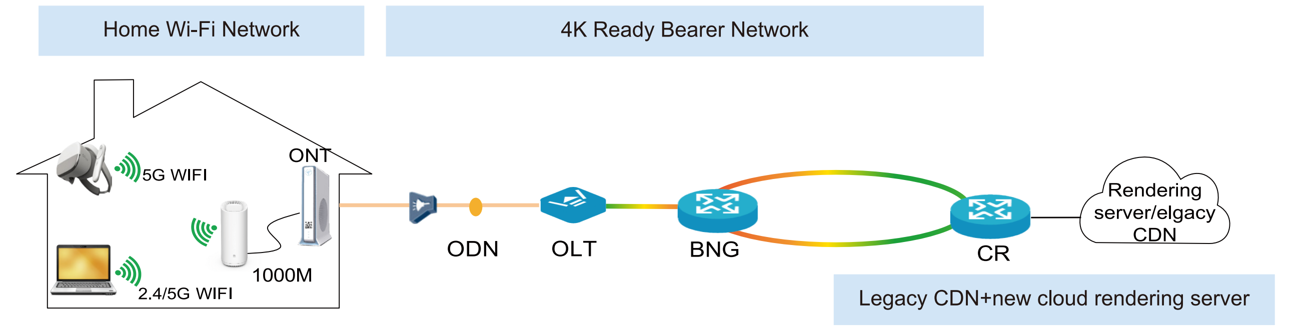

Figure 2-14 Core concept of the Cloud VR network solution

- **Wi-Fi based home network**

  A Traditional 4K STB usually uses a network cable to connect to the network, while Cloud VR terminals require Wi-Fi access. Therefore, a Wi-Fi home network needs to be constructed to bear Cloud VR services. Deploying high-performance Wi-Fi APs is critical.

- **4K ready–based bearer network**

  To quickly and cost-effectively deploy Cloud VR services, adjust the simplified 4K ready bearer network architecture to meet bandwidth and latency requirements of VR services. Adjustments include:

  Upgrading the 10G GPON/EPON to 10G GPON/EPON

  Upgrading and expanding the OLT upstream ports

  Upgrading and expanding the metro network to implement direct OTN transmission with one hop

- **Reusing the CDN/adding new cloud rendering servers**

  Existing CDN resources can be reused for Cloud VR video content distribution. In addition, new cloud rendering servers can be added to implement real-time rendering and streaming for strong-interaction Cloud VR services. CDN and cloud rendering servers are usually deployed in the metro network.

2.2.3.3 Cloud VR Network Planning and Deployment

Home Network Planning and Deployment

Currently, most home Wi-Fi environments cannot meet the Cloud VR service requirements. The key impediments are as follows:

1. Signal interference	2. Signal attenuation	3. Air interface preemption
Wi-Fi uses the CSMA-CA listening backoff mechanism. In the same coverage area, the more devices that exist on a channel, the more fierce the competition, the higher the overhead, and the lower the performance, especially in terms of latency.	The Wi-Fi transmission rate is related to the signal strength. Nearby Wi-Fi APs, the signal is strong and the transmission rate is high. Positions further away from, or separated by walls from, Wi-Fi APs have weaker signals.	Generally, multiple terminals access the home Wi-Fi simultaneously. In addition to VR services, Internet access, downloads, and other video services may occur on the same Wi-Fi network and compete for resources.

Among the preceding factors, signal attenuation can be solved technologically. Users can also identify and avoid the air interface preemption problem. The biggest problem is that of signal interference. Wi-Fi uses public open frequency bands. The number of interfering devices and the interference duration depend on the deployment and usage of neighboring devices. Therefore, providing good transmission performance in a Wi-Fi environment with interference is key for home APs and VR terminals.

The 2.4 GHz Wi-Fi frequency band is small and has only three independent 20 MHz channels. In addition, home devices such as microwave ovens, Bluetooth-enabled devices, and cordless phones use the 2.4 GHz frequency band. In practice, the interference in the 2.4 GHz band is often more severe. However, the 5 GHz band is still being promoted. It has a large number of available channels and supports 80 MHz bandwidth. Through proper channel planning, Wi-Fi channel conflicts between APs can be avoided by using the 5 GHz band, which is more suitable for bearing Cloud VR services.

Considering the network requirements of VR services and the 5G Wi-Fi (802.11ac) capability of mainstream home APs, the requirements for home network deployment are as follows:

- 1. The 5G Wi-Fi frequency band that bears VR services uses the Wi-Fi standard 802.11ac, provides 80 MHz bandwidth, and supports at least 2x2 MIMO.
- 2. It is recommended that operators do not select common consumer-level APs to bear VR services. High-performance APs, such as Huawei WA8011Y, are recommended. These support radar frequency bands and have strong anti-interference capabilities.
- 3. It is recommended that the VR services be carried on an independent 5G band, and that Internet access be carried on different 5 GHz or 2.4 GHz band.

Access Network Planning and Deployment

The access network aggregates end users on the entire network and is the closest to users. Currently, the maximum allowable latency for the access network is 2 ms. Therefore, copper cables are not suitable for carrying Cloud VR. Only FTTx is applicable.

Currently, the mainstream FTTx technologies are GPON and EPON, which can normally meet VR latency requirements. Bandwidth satisfaction becomes the key concern. The following table lists the analysis results.

PON	Capacity	Split Ratio	Convergence Ratio	Bandwidth Available	Satisfied or Not
EPON	1Gbit/s	1:64	50%	32Mbit/s	No (restricted)
		1:32	50%	64Mbit/s	No (restricted)
GPON	2.5Gbit/s	1:64	50%	78Mbit/s	No (restricted)
		1:32	50%	156Mbit/s	No (restricted)
10G EPON/GPON	10Gbit/s	1:64	50%	312Mbit/s	Satisfied
		1:32	50%	625Mbit/s	Satisfied

Table 2–4 VR bandwidth satisfaction by PON technologies with different capacities

Note：Bandwidth Available = Capacity / (Split ratio / Convergence ratio)

The minimum home bandwidth requirement is 260 Mbit/s. Neither EPON nor GPON bear Cloud VR services on a large scale. VR services are restricted and can be provisioned only to a small number of users depending on the remaining bandwidth of EPON or GPON.

To meet large-scale VR bandwidth requirements, FTTx access needs to be gradually upgraded to 10G EPON/10G GPON. Then, even if the split ratio is 1:64 and convergence ratio is 50%, each user would obtain 312 Mbit/s bandwidth, meeting the current Cloud VR bearing requirements.

Metro Network Planning and Deployment

In the current phase, Cloud VR services can be carried on the existing 4K Ready bearer network, as shown in the following figure.

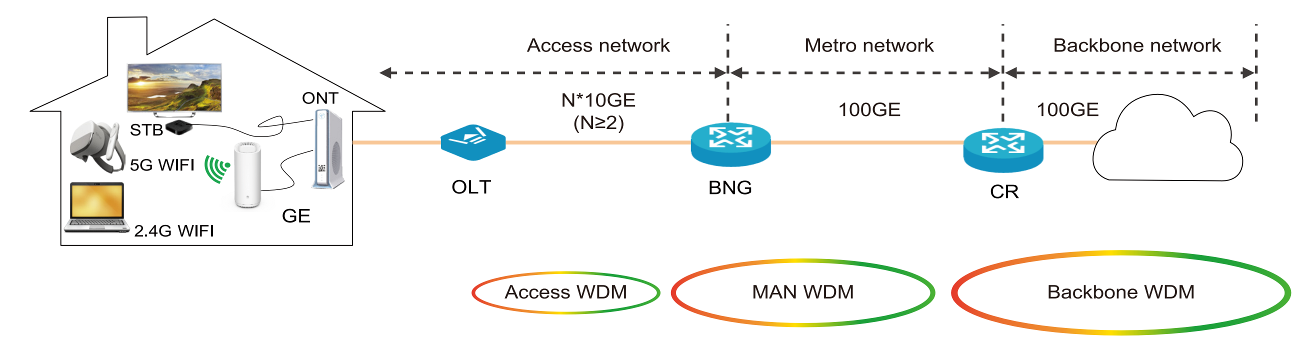

Figure 2-15 Using the 4K Ready network to carry Cloud VR services

The key deployment requirements for the metro network are as follows:

- **Network flattened to reduce invalid convergence**
  The OLT access device must be directly connected to the broadband network gateway (BNG) of the metro network through a 10 GE interface with a recommended single-slot capacity of at least 240G. The BNG uses 100GE to connect to the metro core CR, which supports 400G clustering.

- **BNG moving downwards**
  Moving BNG downwards makes deploying VPLS on the network simpler. In addition, CDN and cloud rendering servers can be flexibly deployed to reduce latency.

- **OTN to CO**
  A large number of fibers need to be routed to flatten the network. The BNG can be moved further downwards to the metro edge or OLT sites using WDM equipment to provide an infrastructure pipe with ultra-high bandwidth, low latency, and zero packet loss.

- **Monitoring network link usage in real time**
  If the link usage exceeds the VR threshold, capacity can be expanded in a timely manner to prevent congestion and packet loss during traffic bursts.

2.2.3.4 Reusing Existing Network Channels to Carry Cloud VR Services

The Cloud VR bearer network is reconstructed and evolved based on the 4K Ready bearer network. Currently, the IPTV service mainly uses the dual-channel solution. That is, the STB accesses a dedicated IPTV port of the ONT, performs dialing independently, and uses a dedicated IP address. Internet access uses a PPPoE channel provided by the ONT.

It is recommended that Cloud VR services reuse existing network channels so that, with special network deployment or reconstruction, VR terminals can access the network as quickly as can mobile phones.

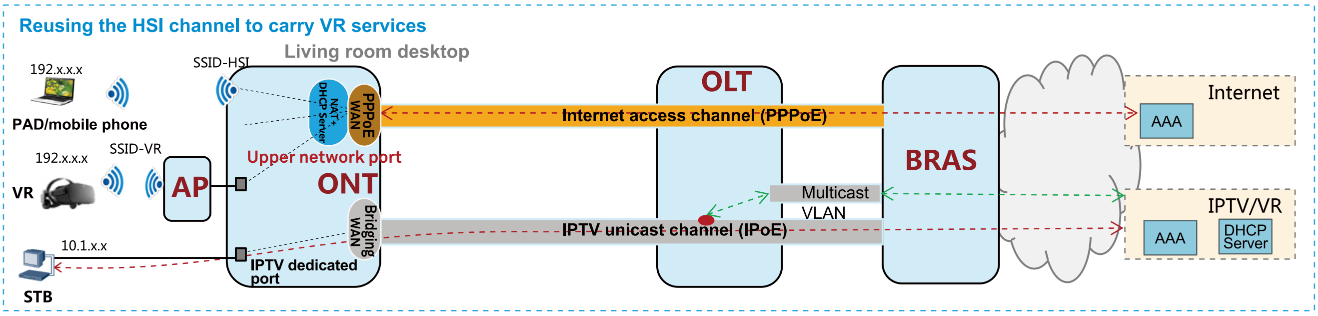

Figure 2-16 Reusing existing network channels to bearer VR services

2.2.3.5 QoS Planning and Deployment for Cloud VR Services

Different service types have different network requirements. Therefore, services need to be classified. To provide QoS assurance, services of different types have different port priorities. For example, live IPTV and VR services that are transmitted through UDP multicast are sensitive to packet loss and affect a large number of users. VR strong-interaction services are sensitive to latency. Packets of such services need to be assigned high priorities.

Services	802.1p	DSCP	EXP	Wi-Fi WMM
Live IPTV, VR live broadcast (UDP), and VR strong-interaction services	5	101110 (EF)	5	AC_VI
IPTV VOD, VR VOD, and VR live broadcast (TCP)	4	100010(AF4)	4	AC_VI
Internet access service	0	000000（BE）	0	AC_BE

Table 2-5 Priority allocation suggestions

When VR services are transmitted over existing network channels, Cloud VR traffic and Internet access traffic have an aggregate rate limit. QoS methods such as HQoS and DAA are commonly used to prevent bandwidth preemption.

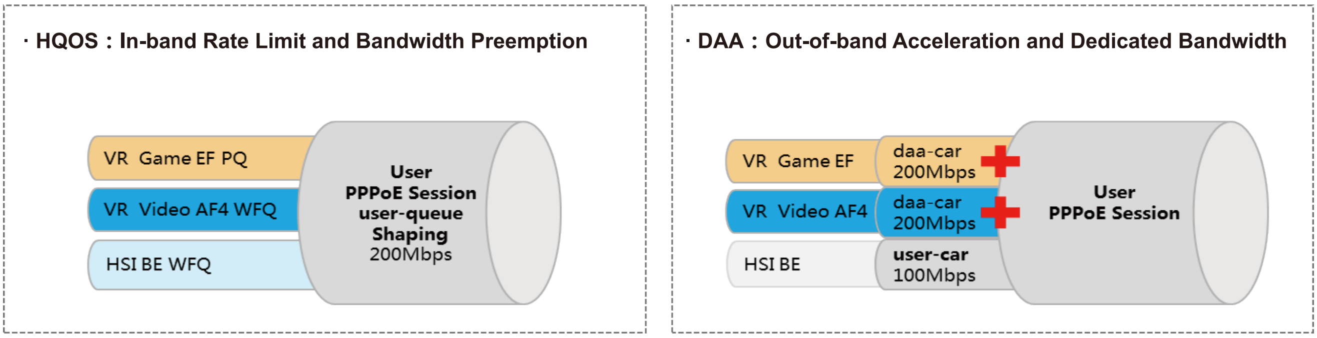

Figure 2-17 Common QoS solutions

2.2.3.6 Cloud VR O&M Solution

Currently, the Cloud VR O&M system is incomplete. Cloud VR O&M is still a big problem. According to 4K IPTV poor QoE classifications, more than 60% of problems occur on the home Wi-Fi side. Therefore, it is recommended that the Wi-Fi Sense solution be used to analyze home Wi-Fi KPIs for Cloud VR service assurance. The core component of this solution is the Netopen server, which communicates with the ONTs and APs dedicated to Cloud VR services to obtain Wi-Fi indicators for comprehensive analysis, home network fault location, and optimization suggestions. The implementation process is as follows:

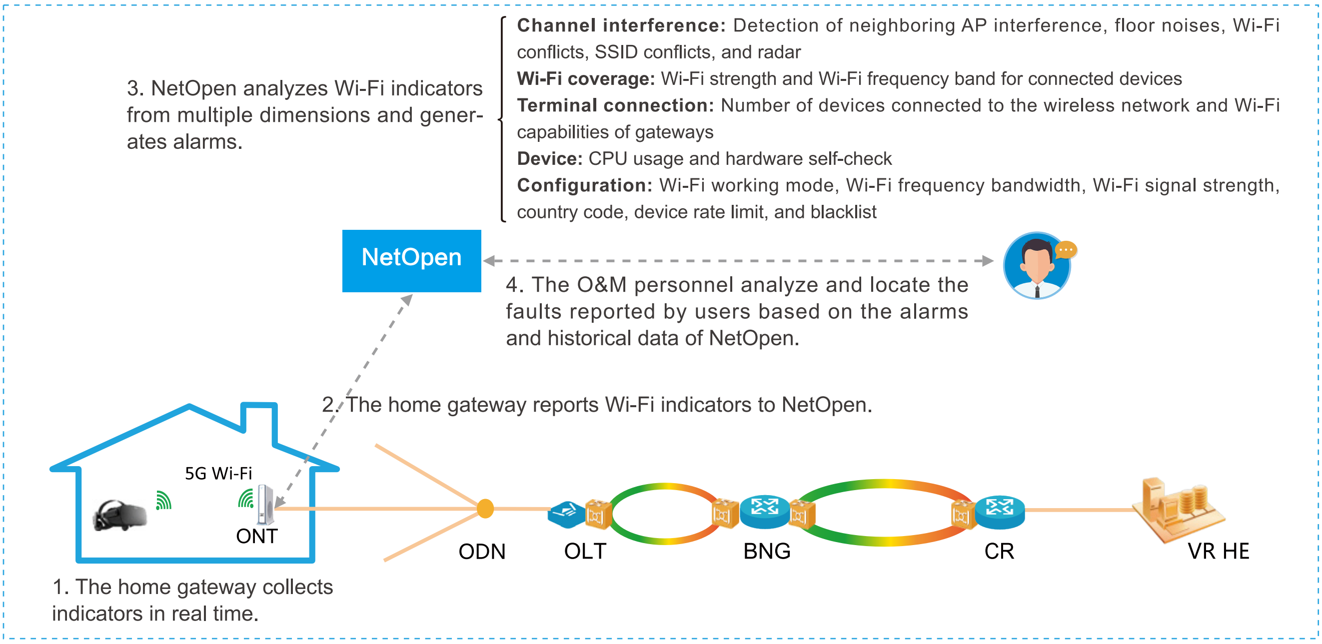

Figure 2-18 Wi-Fi Sense experience assurance

2.2.4 Selecting and Deploying Cloud VR Terminal

2.2.4.1 Cloud VR Terminal Planning

Cloud VR terminals mainly access the network through Wi–Fi. The terminals are cordless, movable, comfortable, and interactive, and can be easily configured and installed. Therefore, these terminals can be easily marketed to users on a large scale.

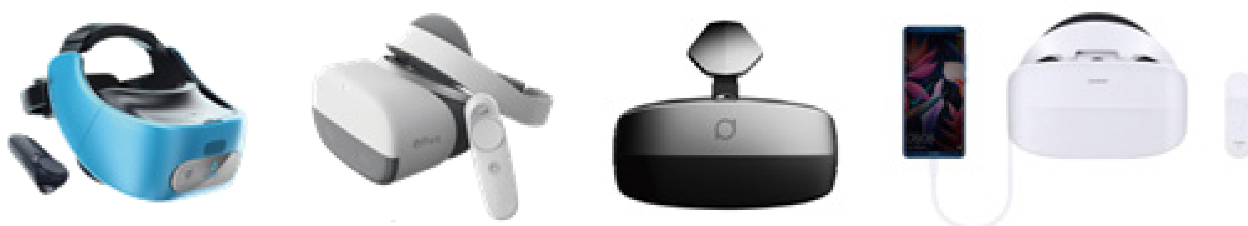

Figure 2-19 Cloud VR terminal form

In the Cloud VR solution, a Cloud VR terminal needs to connect to the Cloud VR video service platform, strong–interaction Cloud VR service platform, screen mirroring system, and STB, as shown in the following figure.

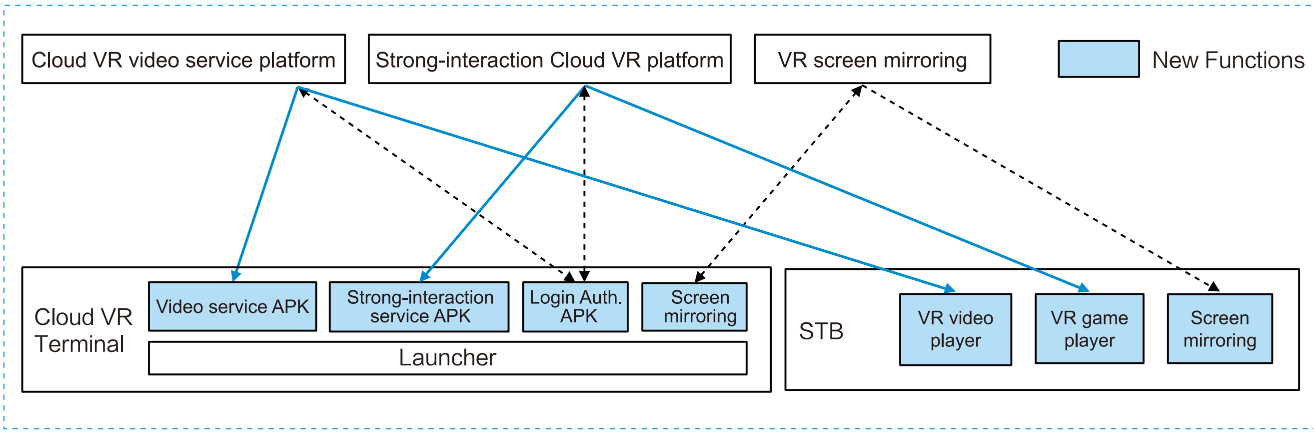

Figure 2-20 Cloud VR terminal solution

In addition to the functions of a local VR terminal, a Cloud VR terminal also needs to support the Launcher, video service APK, strong-interaction service APK, login authentication, and screen mirroring service. These enable them to obtain the orchestrated video and strong-interaction content from the service platform server.

A Cloud VR terminal uses screen mirroring to share content to an STB. The STB uses a player to play the VR content on a screen.

2.2.4.2 Function Requirements for Cloud VR Terminals

The key functions and corresponding parameter specifications of a Cloud VR terminal are as follows:

VR Terminal Function	Parameter	Specifications	Remarks
Screen	Screen type	Quick-response LCD or OLED screen	
	Resolution	Single eye resolution of 1080x1200 or higher	
	Refresh rate	Not lower than 70 Hz	
	FOV	Not less than 90 degrees	
	Nearsighted friendliness	Supporting glasses or providing the focal length adjustment function	
	Eye comfort mode	Low blue light certification	Optional
Space positioning	Degree of freedom (DoF)	3 DoF or 6 DoF; 6DoF recommended for high-end game users	
Communication capability	Wi-Fi	Supporting 802.11ac 5G Wi-Fi with 2x2 MIMO	
Processor	CPU	Qualcomm Snapdragon 820, Samsung Exynos 7420, or CPUs with equivalent or higher capabilities	
Sensor	Terminal sensor	9-axis sensor (gyroscope, accelerometer, and geomagnetic meter)	
		Distance sensor (ultrasonic, infrared, optical, and so on)	
	Handle sensor	9-axis sensor (gyroscope, accelerometer, and geomagnetic meter)	
Codec		H.264/H.265	
Audio		External/built-in earphone, which can generate 3D audio	
Battery life		Not less than 2 hours	

Weight	Terminal weight, battery included	<500g	
Fingerprint payment		Supporting quick payment by fingerprint authentication	New function
Launcher		Launcher application icons and background	New function
Video service APK		APK integrating VR live broadcast, VR 360° video, VR education, and VR IMAX.	New function
Strong-interaction service APK		SDK connecting to the Cloud VR games	New function
		Integrated Cloud VR game application APK	New function
User authentication		User login authentication center supporting login operation and status management	New function
Screen mirroring function		Connecting to the screen mirroring system on the live network to transmit video and game application screen information	New function
System upgrade		Connecting to the terminal management system on the live network and supporting incremental upgrade	New function
Reprojection		Implementing asynchronous terminal-cloud rendering collaboration with the cloud rendering platform	

Table 2-6 Key functions of a Cloud VR terminal

2.2.4.3 Interconnection Between Cloud VR Terminals and Service Platforms

Launcher

The Launcher page is displayed for users. It generally contains a VR application scenario logo, user center, and personalized settings. The style, colors, and functions of the UI can be customized.

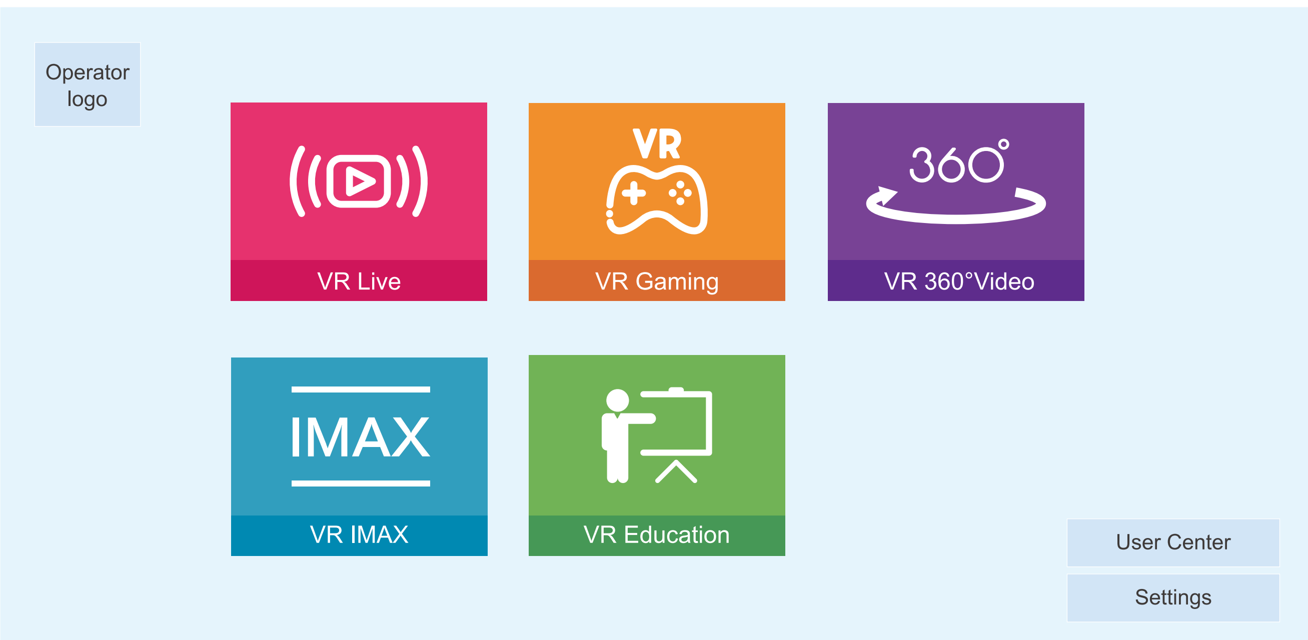

Figure 2-21 Launcher

Interconnection with a Video Service APK

To access and connect to the Cloud VR video service platform, a terminal needs to use a video service APK to continue exchanging heartbeat messages with the service platform.

Interconnection with the Strong-Interaction Service APK

A terminal needs to use strong-interaction service APKs, including a Cloud VR portal and a Cloud VR protocol library. The Cloud VR protocol library interacts with the cloud rendering platform and uploads operation data, whereas the Cloud VR portal provides interfaces for users to access the strong-interaction service platform, including product display and classification.

User Login Authentication SDK

User login authentication methods:

- **Mobile phone login**
  Perform login authentication by receiving an SMS verification code or using a mobile app to authorize or unauthorize VR users. This solution enhances user loyalty to existing mobile phone services of operators and helps to form a unified account center system.

- **Login authentication in a Cloud VR terminal**
  The authentication page runs on the VR terminal, and the terminal authenticates users.

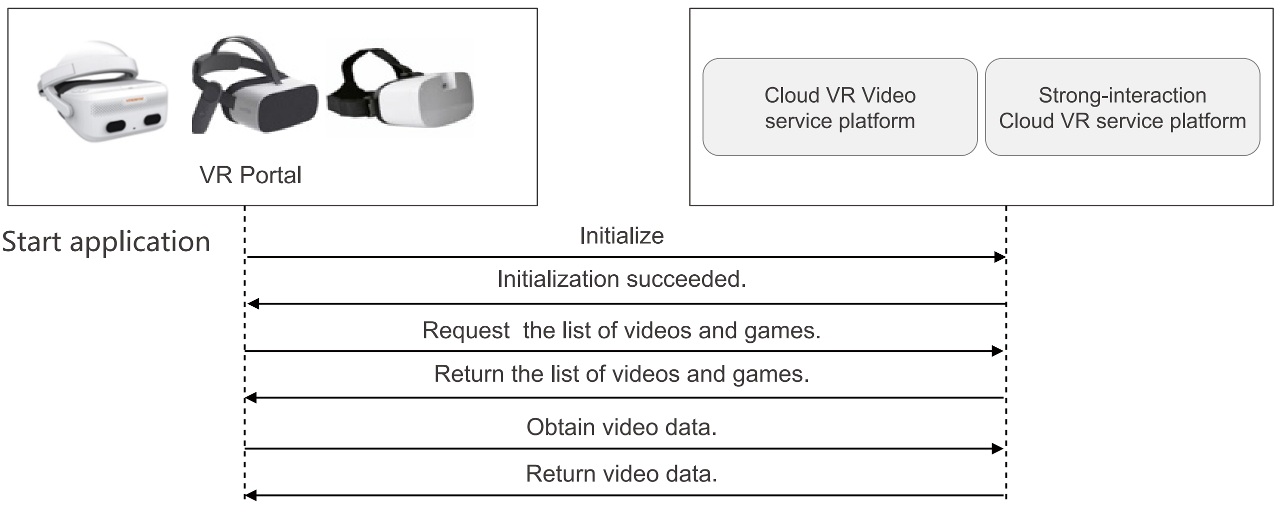

Figure 2–22 Interaction process of user authentication and login

Screen Mirroring Function

The screen mirroring function is new. A user can synchronize the content displayed on a Cloud VR terminal to a TV screen by sending screen mirroring instructions on the terminal. After user login authentication, the Cloud VR terminal is bound to the STB, and a screen mirroring channel is used to realize screen mirroring.

System Upgrade

A Cloud VR terminal must support system upgrade, including version update, new feature addition, and problem rectification. The upgrade function can be implemented by using the terminal management platform on the live network according to the TR069 protocol.

Reprojection

Unlike a local VR terminal, a Cloud VR terminal must support reprojection to work with the cloud rendering system to implement asynchronous terminal–cloud rendering and keep MTP below 20 ms.

Communication Capability

Cloud VR terminals connect to the service platform over Wi–Fi. Because of high service bandwidth and latency requirements, these terminals must support 5G Wi–Fi.

2.3 Cloud VR Video Service

Operators who have traditional video service platforms, such as IPTV/OTT platforms, can quickly construct a Cloud VR video service platform based on these traditional platforms. A Cloud VR video service platform requires a VR VOD system and a VR live broadcast system.

VR videos have a higher bit rate than traditional videos, with current, full-view 4K VR videos having a single-user bit rate of 40 Mbit/s. Therefore, operators' Cloud VR video service solutions must support high bit rates, which will support cloud CDN systems, network transmission capabilities, terminal decoding capabilities, etc. In addition, operators must improve the real-time transcoding and slicing capabilities for VR live broadcast systems that have requirements for strict timing.

2.3.1 Overall Design of the Cloud VR Video Solution

2.3.1.1 Solution Composition

The Cloud VR video service solution consists of three parts: Cloud VR video service platform, network, and Cloud VR terminals.

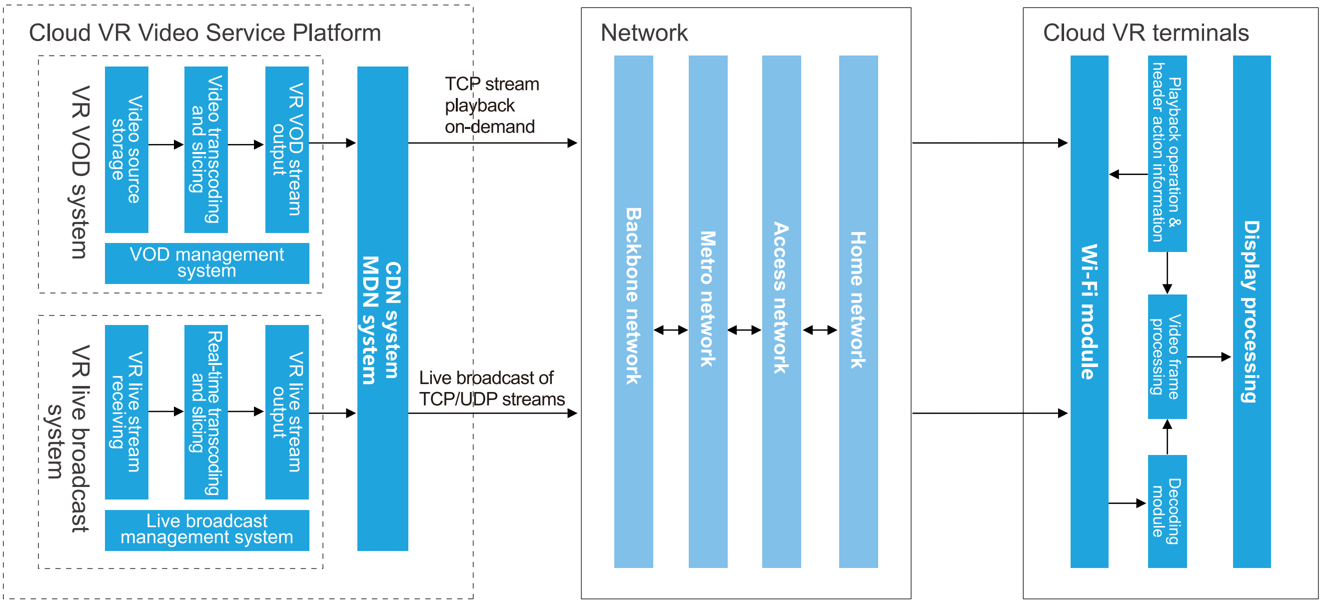

Figure 2-23 Cloud VR video service solution

1. Cloud VR video service platform

This platform is responsible for transcoding, slicing, and outputting streams. It consists of the VR VOD system, VR live broadcast system, MDN system, and CDN system. The VR VOD system and VR live broadcast system have to be created, while the platform uses a full-view transmission solution. With improvements to the VR video resolution, the transmission solution will gradually develop to the FOV transmission solution.

- **New VR VOD system:** Consists of a management system and a production system. The management system provides operation personnel with media resources and program production management. The production system transcodes and slices original video materials and then outputs the streams to the MDN system.

- **New VR live broadcast system:** Consists of a management system and a production system. The management system orchestrates and manages live broadcast contents, while the production system processes video streams in real time. Because live broadcasting has strict timing requirements, servers with high performance must be configured for the broadcast system. In addition, high-performance graphics cards must be configured for transcoding and slicing.

- **Reusing the existing MDN system and CDN system on the live network for interface adaptation:** As an incremental service, Cloud VR can reuse MDN and CDN resources on the live network. The VR VOD system and VR live broadcast system are connected to the MDN system through standard interfaces. VR program sources are entered into the MDN system and then distributed by the CDN system so that users can watch the programs.

2. Network

Transport optimization and experience management enhancement can be implemented based on the 4K-ready network. For example, QoS guarantee, home high-performance 5G Wi-Fi, and Cloud VR service experience guarantee designs can be deployed. In addition, due to characteristics such as high concurrency and the heavy traffic of VR live broadcast services, multicast and M-FOV solutions must be deployed in order to reduce network loads and guarantee optimal user experience.

3. Cloud VR terminal

Currently, the mainstream resolution of VR videos is 4K, and the single-eye resolution of VR terminals must be 1K or higher. The terminals must also support 4K decoding capabilities and provide communication capabilities that have higher performance.

2.3.1.2 Key Requirements

In the current phase, the key requirement of the solution is to support full-view transmission solutions. These include the "cloud-based full transmission + terminal-based full decoding" solution, the "cloud-based full transmission + terminal-based partial decoding" solution, and the multicast solution based on full-view transmission.

The mature application of FOV transmission technologies such as TWS and M-FOV will promote the popularity of higher-definition VR videos. Evolution of transmission solutions is only used to guide the development of subsequent solutions and is not a key requirement of the current solution.

Support for full-view transmission solutions

A full-view transmission solution can transmit 360-degree wrap-around images to terminals. If these images need to be switched because a user has rotated the head, the terminal can immediately complete operations such as code stream parsing, video decoding, and image rendering. Currently, cloud, network, and VR terminals support 4K VR video transmission and playback.

1. "Cloud-based full transmission + terminal-based full decoding" solution

This solution is used by most VR terminals, meaning a full-view 4K VR video source is prepared on the cloud. After the entirety of the full-view contents is encoded, the contents are transmitted based on 4K quality requirements. The terminal must then decode all VR contents.

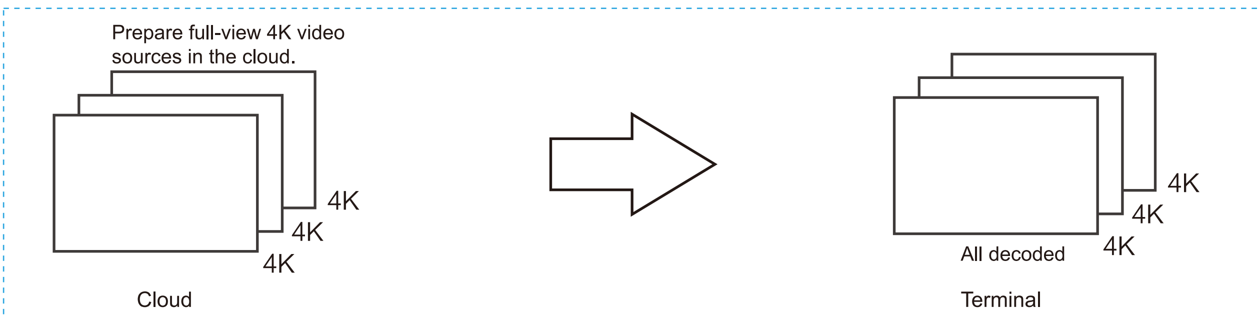

Figure 2-24 "Cloud-based full transmission + terminal-based full decoding" solution

Module Name	Requirements for Key Functions
VR VOD system and VR live broadcast system	Support transcoding and slicing based on 4K, full-view contents. The live broadcast system must support real-time processing.
MDN and CDN systems	Support a bit rate of at least 40 Mbit/s.
Cloud VR terminals	Support the decoding and playback of 4K video streams.

Table 2-7 Requirements for key functions of the "Cloud-based full transmission + terminal-based full decoding" solution

The main advantage of this solution is that any content with the same quality can be seen at any time when switching views. However, some unnecessary image contents are also transmitted and decoded, and terminals require decoding capabilities with the same resolution as the contents.

2. "Cloud-based full transmission + terminal-based partial decoding" solution

This solution applies only in scenarios where a small amount of 8K content exists. The decoding chips on most VR terminals do not support the decoding of 8K VR videos, but this solution enables these VR terminals to play 8K VR videos after the terminal software is upgraded. This is made possible based on their 4K hardware decoding capabilities.

In this solution, high-quality 8K full-view video sources are prepared on the cloud, after which a full-view video is divided into multiple tiles. Each of these tiles is then encoded and transmitted with the same quality. The terminals can locate these tiles according to the current view and perform decoding. The terminals only then need to decode the VR contents in the area that is visible, effectively reducing the requirements for the decoding capabilities of terminals. For more information, see Figure 2-25.

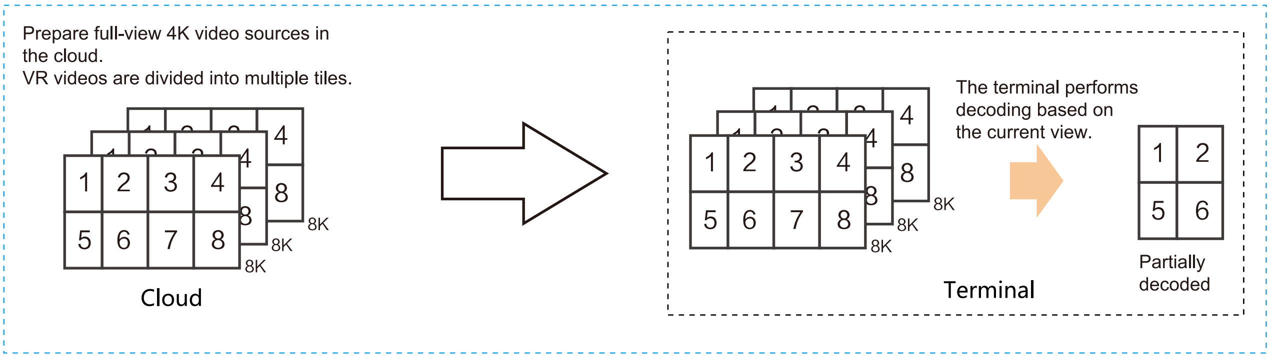

Figure 2-25 “Cloud-based full transmission + terminal-based partial decoding” solution

Module Name	Requirements for Key Functions
VR VOD system and VR live broadcast system	Support the division of full-view video images into multiple tiles, as well as the encoding and transmission of each tile. The live broadcast system must have the real-time processing capability.
MDN and CDN systems	Support a bit rate of at least 40 Mbit/s.
VR terminals	Support the decoding and playback of 4K video streams. Find a tile in the current view and then decode the tile.

Table 2-7 Requirements for key functions of the "Cloud-based full transmission + terminal-based partial decoding" solution

3. Multicast solution based on full-view transmission

As the time taken to watch VR live broadcast programs lengthens and the concurrency rate increases, VR live broadcast services are prone to network congestion, which can deteriorate user experience. If this occurs, the RTP or RTSP over UDP multicast mode can be used to transmit VR live streams. The multicast mode can improve user experience, reduce operators' network bandwidth consumption, and reduce CDN deployment costs. Based on the full-view transmission mode, the VR live broadcast system injects live contents into the MDN system in real time. The VR terminals join multicast groups to obtain the corresponding full-view code streams, as shown in the following figure.

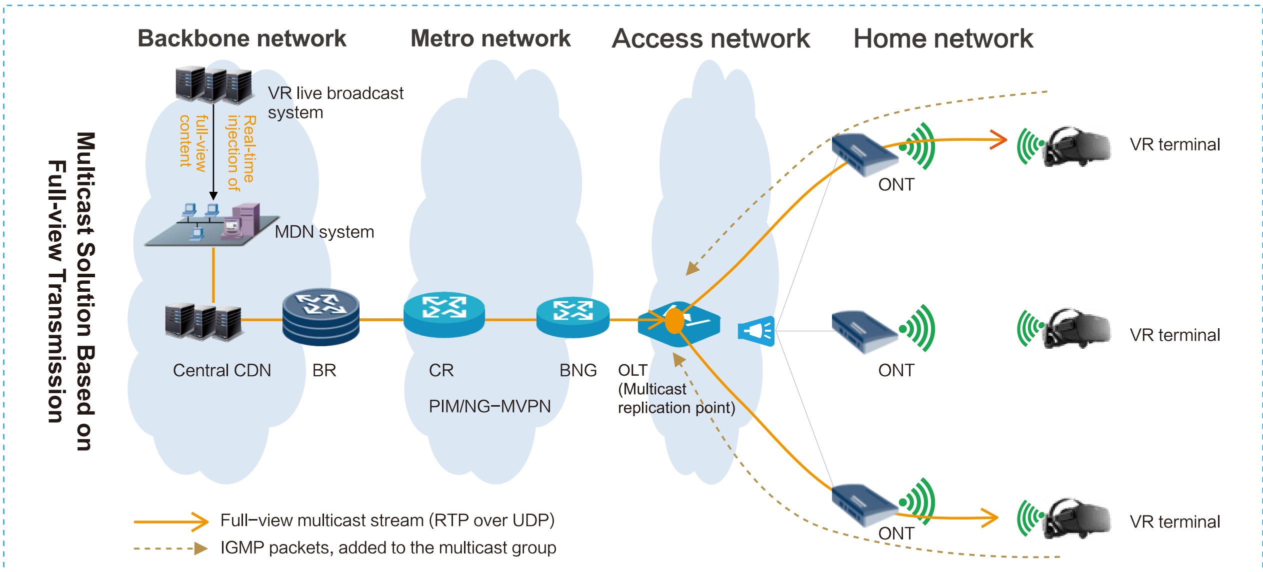

Figure 2-26 Multicast solution based on full-view transmission

Module Name	Requirements for Key Functions
VR live broadcast system	Supports real−time transcoding based on the RTP or RTSP protocol.
MDN and CDN systems	Support a bit rate of at least 40 Mbit/s.
Network	The metro network supports the forwarding of multicast streams. The multicast replication point can be a BNG or OLT.
Cloud VR terminals	Support the decoding and playback of RTP or RTSP over UDP video multicast streams. Support the IGMP protocol and join multicast groups.

Table 2-9 Requirements for key functions of the multicast solution based on full-view transmission

Transmission solution evolution

With continuous improvements to the resolution, the full-view transmission solution will greatly improve the bandwidth requirements for network transmission and home Wi-Fi, which will require terminals to have improved decoding performance. To satisfy this requirement, the industry proposes the FOV transmission solution with differentiated transmission VR images that are based on perspective. The following describes the tile wise (TWS) transmission solution and the M-FOV solution as a reference for the FOV transmission solution.

1. TWS transmission solution

The TWS transmission solution uses on-demand transmission, partial decoding, and view-based self-adaptive policies. This allows the solution to dynamically select high-quality video blocks based on users' real-time watching areas. This effectively saves network traffic costs and reduces the requirements for terminal decoding capabilities.

As shown in the following figure, when on the cloud side, the VR video is divided into multiple tiles and each tile is encoded separately. A high-quality tile is then selected in the perspective area for streaming, and a low-quality VR full-view video code stream is prepared based on the view information reported by the terminal. The terminal then obtains a low-quality, full-view code stream and a high-quality tile stream in the perspective area, after which the full-view code stream can guarantee optimal user experience when switching the user's view.

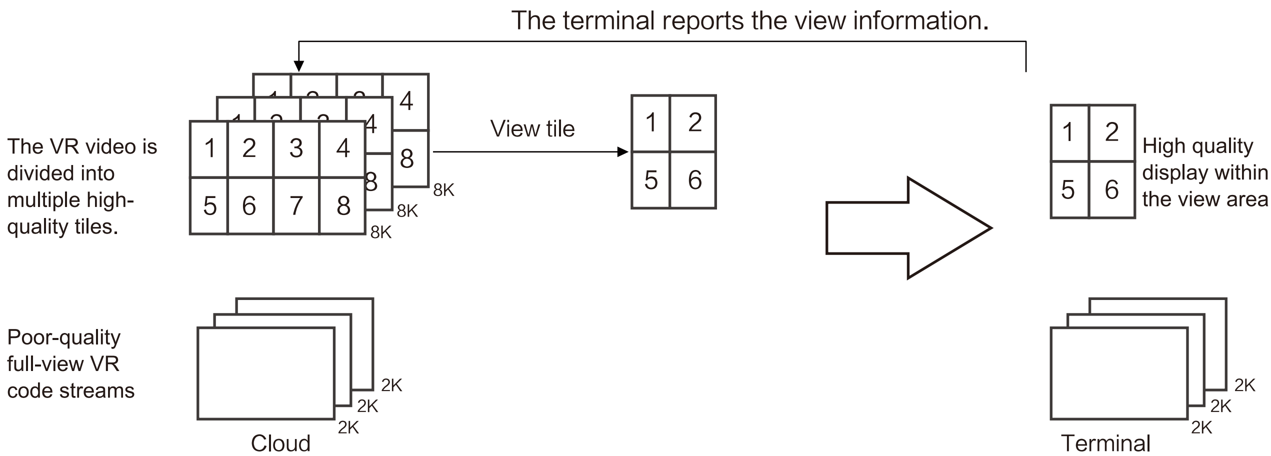

Figure 2-27 TWS-based VR content transmission solution

2. M-FOV solution

When using the M-FOV solution, the FOV transmission solution is applied to the multicast solution in live broadcast scenarios. High-quality video streams in the view area are also pushed from network edges, such as OLTs or ONTs to VR terminals, ensuring fast view switching for users.

As shown in the following figure, the M-FOV is deployed on the OLT. The OLT receives the full-view content that is pushed by the VR live broadcast system. As a unicast server, the OLT quickly pushes the corresponding FOV images to the VR terminal. The M-FOV solution reduces the bandwidth requirements for home Wi-Fi and access networks as well as the requirements for the decoding capabilities of VR terminals. In addition, the M-FOV solution guarantees user experience by quickly switching images if the view of the VR terminals is changed.

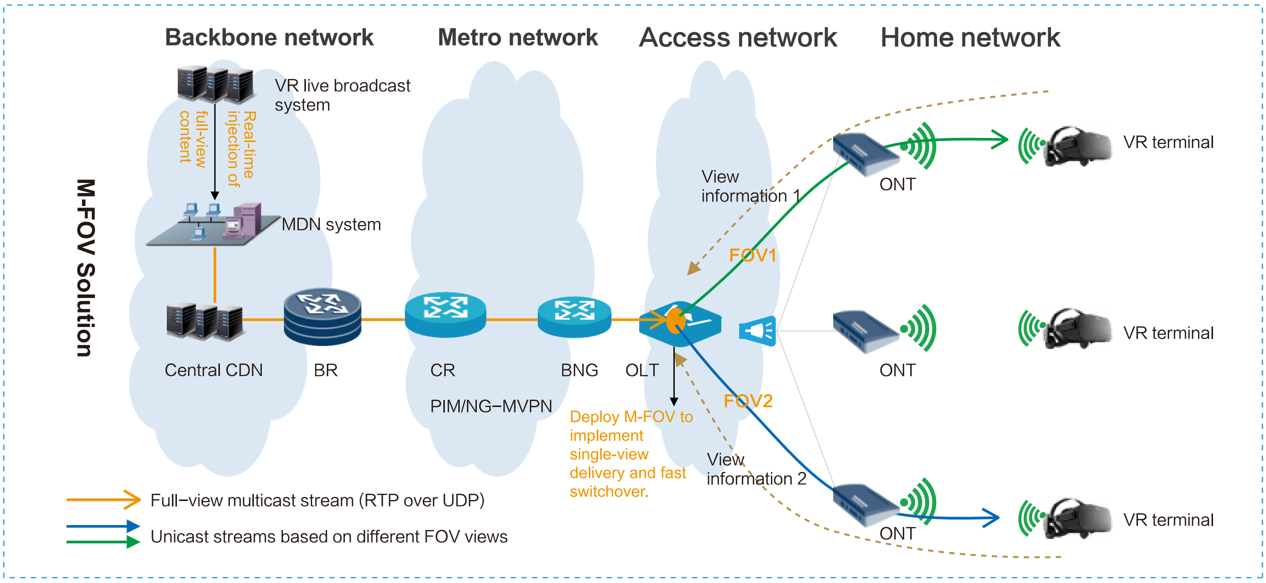

Figure 2-28 M-FOV-based multicast solution

2.3.2 Planning and Deploying the Cloud VR Video Service Platform

2.3.2.1 Server Deployment on the Platform Side

The Cloud VR video service platform consists of the VR VOD system, VR live broadcast system, CDN system, and MDN system. The VR live broadcast system and VR VOD system must be newly deployed, while the MDN and CDN systems can reuse the live-network video platform.

Deployment of the VR VOD and live broadcast systems

- 1. Deployment of a high-performance server and the configuration of high-performance graphics cards for live broadcast transcoding
  The VR VOD and live broadcast systems require different subsystems to implement functions such as VR video access, transcoding, publishing, storage, and media asset operations. The platform must provide physical machines or virtual machine resources (including CPUs, RAM, HDDs, and network adapters) for these subsystems. In addition, 8-core CPUs running at 2.5 GHz or more must be installed, as well as 32 GB of RAM or greater, for these subsystems. The live broadcast system transcodes live streams in real time, meaning a higher-performance server must be configured. For example, the server must be equipped with at least a 16-core CPU, 64 GB of RAM, and a high-end graphics card (such as a NVIDIA Tesla P4). A RAID 0+1 or RAID 0 hard disk is recommended for such a server.

- 2. Transcoding performance requirements
  After transcoding, the VR live broadcast system and VR VOD system must output video streams that meet the following requirements: 4K video streams that are encoded with H.264, a 30 FPS frame rate, a 40 Mbit/s bit rate, 128 kbit/s AAC, and a 48 kHz sampling rate.

- 3. Loosely coupled and scalable architecture
  Each subsystem module in VR live broadcast and VOD systems can be expanded. If a module encounters a performance bottleneck, the operator only needs to add servers that run the module, which will not affect other modules.

- 4. System reliability deployment
  Each subsystem server uses a redundant and fault-tolerant architecture, and all modules are deployed in redundancy mode. This ensures that any server faults will not interrupt system services.

- 5. Deployment of a complete monitoring system, ensuring instant alarms for any hardware or software faults.

CDN deployment

- **CDN server deployment location**
  The contents produced by the Cloud VR video service platform are distributed by the CDN system. In addition to the central CDN system that is deployed in the provincial center, a level-2 CDN system must be deployed in the central equipment room of each city.

- **Deployment of high-performance servers to support VR high bit rates and meet concurrent requirements**
  The bit rate of 4K VR video streams reaches 40 Mbit/s, which is higher than the current bit rate requirement of common 4K videos. Therefore, the CDN system is required to support VR videos with high bit rates. Based on the planned number of VR users and the OTT video concurrency rate (for example, 5%), CDN performance must be evaluated to determine whether it meets concurrent requirements before service provisioning.

- **CDN storage capacity planning**
  VR videos have high bit rates and large video files, leading them to have high requirements of storage capacities. Therefore, the CDN storage capacity needs to be planned based on the introduced VR program sources.

2.3.2.2 Interconnection Between the VR VOD/Live Broadcast Systems and the MDN System

After transcoding and slicing VR videos, the VR VOD or live broadcast system must inject the VR video content into the MDN or CDN system for distribution. Therefore, it is essential that the VR VOD or live broadcast system is connected with the MDN system during deployment of the Cloud VR video service platform. Operators should pay attention to the following:

- Ensure that the IP addresses of the VR VOD or live broadcast system and the MDN system are reachable and firewall ports are open.

- After the VR VOD or live broadcast system and the MDN system are interconnected, and sessions are set up based on MDN system specifications, they must complete authentication. After MDN system authentication is complete, the MDN system obtains videos from the VR VOD or live broadcast system to inject contents.

2.3.3 Planning and Deploying the Cloud VR Video Service Network

2.3.3.1 Requirements of the Cloud VR Video Service Network

Currently, Cloud VR video services are transmitted in full-view mode. When compared with 4K videos, VR videos have higher bit rates, require larger network throughput, and need higher bandwidth. Network indicators, such as packet loss rate and latency, impact network throughput, which indirectly affects user experience.

Service Scenario	Indicator	Reference Value
VR video service	Bandwidth	≥60Mbit/s
	RTT (Note 1)	≤20ms
	Packet loss rate	9E-5

Table 2-10 Network requirements for Cloud VR video services

Note 1: VR video services do not require the network RTT to be less than 20 ms. However, a smaller RTT means a shorter image loading time during channel switching and video playback. If the loading time is not important, an RTT of 30 ms to 40 ms is acceptable.

2.3.3.2 Cloud VR Video Service Network Solution

Strong-interaction Cloud VR services have higher requirements on networks than Cloud VR video services. During the deployment planning for the Cloud VR service network, the strong-interaction Cloud VR service requirements will prevail. For details about the deployment planning of the Cloud VR video service network, see section 2.2.3 Planning and Deploying Network for Strong-interaction Cloud VR Services.

2.3.4 Selecting and Deploying Cloud VR Terminal

The terminal solution for the Cloud VR video service is similar to that of the strong-interaction service. For details, see section 2.2.4 Selecting and Deploying Cloud VR Terminal. Compared with terminals used for the strong-interaction service, the terminals for the Cloud VR video service focus on requirements that affect viewing experience, such as the screen resolution, and have lower requirements of capabilities, such as positioning interaction, reprojection, and asynchronous distortion.

2.4 Cloud VR Screen Mirroring Solution

Cloud VR screen mirroring is a process of synchronizing the content that a user views in a VR terminal to an STB. This is done through a specific program and the content is then displayed on a TV screen. Screen mirroring enables images in the virtual world to be shared with others during a user's VR experience, which is a rigid requirement of VR services.

Current mainstream screen mirroring modes include local screen mirroring and cloud-based screen mirroring. When using local screen mirroring, a VR terminal directly compresses and encodes the video content that is watched by a user, and then sends the compressed and encoded content to the STB for processing and playback. When using cloud-based screen mirroring, the cloud screen mirroring system synchronizes messages between the VR terminal and STB. The STB then initiates stream pushing to the cloud CDN system or cloud rendering system and pushes streams to the STB. Currently, the typical local screen mirroring mode is DLNA, however, compared with cloud-based screen mirroring, local screen mirroring has the following restrictions:

- It is difficult to ensure playback quality. VR terminals generally use Wi-Fi access, which requires high bandwidth, and local screen mirroring requires the VR terminals to push the viewed content to STBs through Wi-Fi. As a result, the requirements of home Wi-Fi transmission are doubled. This means that playback quality cannot be guaranteed with existing Wi-Fi technology.

- Home network restrictions. VR terminals and STBs must be in the same LAN. In actual scenarios, VR and IPTV services are carried on different planes and cannot interact locally.

- Power consumption is high, and the duration for which VR terminals are used is halved. During local screen mirroring, VR terminals need to perform extra encoding and streaming pushing operations, increasing power consumption and decreasing terminal life.

Therefore, the cloud VR screen mirroring solution is recommended as it can guarantee a high-quality viewing experience without changing the way in which the existing home network is deployed.

2.4.1 Cloud-based Screen Mirroring

Cloud-based screen mirroring requires a screen mirroring system that is established on the cloud. The cloud-based screen mirroring system searches for user accounts to bind to VR terminals and STBs in pairs. The VR terminals and STBs do not need to communicate with each other, and do not occupy extra home Wi-Fi resources. In cloud-based screen mirroring, two copies of traffic must be transmitted in addition to VR video streams or rendering streams.In addition, the cloud CDN or cloud rendering system must push screen mirroring streams to STBs. Figure 2-29 shows this process.

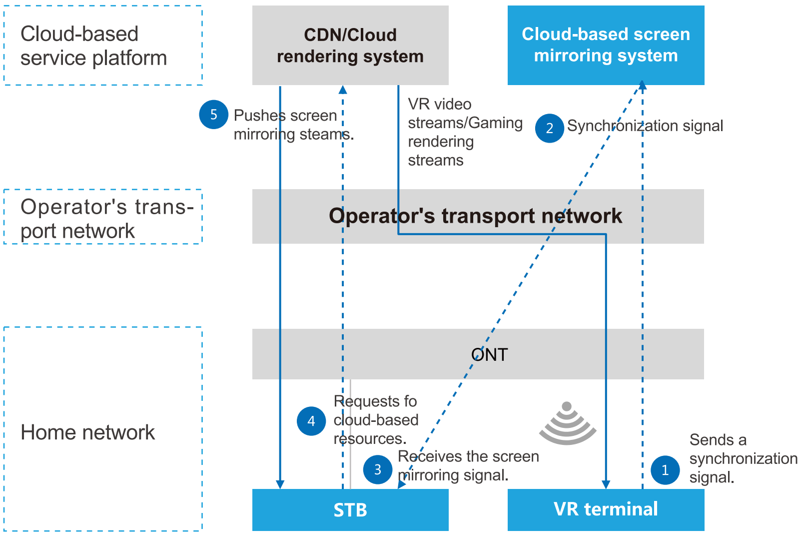

Figure 2-29 Cloud-based screen mirroring

The process is described as follows:

- The VR terminal initiates a screen mirroring operation and sends a synchronization request.
- After receiving the screen mirroring request, the cloud-based screen mirroring system queries the user account, finds the corresponding STB, and sends a screen mirroring synchronization signal. During screen mirroring of a video service, the VR terminal must periodically synchronize video playback information (such as the playback progress and the viewing coordinates) to the STB through the cloud-based screen mirroring system. This will ensure that the video playback image of the STB is consistent with that of the VR HMD.
- The STB receives the screen mirroring signal sent by the cloud-based screen mirroring system.
- The STB requests resources from the cloud.
- After receiving the request, the CDN or cloud rendering system pushes video streams to the STB.

2.4.2 Screen Mirroring Solution Evolution

With continuously growing Cloud VR screen mirroring services, screen mirroring traffic will also increase significantly. The cloud-based screen mirroring solution will improve network capacity requirements and cloud system performance. On one hand, the network transmits two copies of traffic, meaning that when the user concurrency rate is high, network expansion costs must be increased. On the other hand, since the cloud processes large amounts of synchronization signaling, the cloud system performance must be improved. This will ensure that the latency does not increase and user experience is not reduced in the case of a large number of concurrent users.

Therefore, in future screen mirroring solutions, the cloud-based screen mirroring function must be implemented by the ONT (the ONT screen mirroring proxy solution), as shown in Figure 2-30.

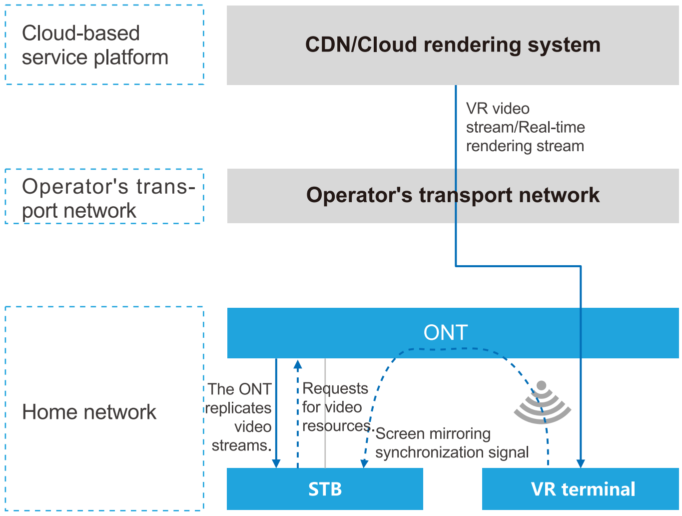

Figure 2-30 ONT screen mirroring proxy solution

In the home network, the ONT is used to process screen mirroring requirements and replicate screen mirroring streams. This ensures that no extra Wi-Fi resources are occupied, while resolving the issues of cloud screen mirroring occupying operators' bandwidth resources and screen mirroring synchronization being delayed due to sharp increases in the number of users in the future.

03
Suggestions for Cloud VR Operation and Ecosystem

3.1 Suggestions for Scenario and Content Selection

3.1.1 Suggestions for Scenario Selection

- **The number of users is less than 100,000.**
  Operators are advised to develop in areas that can provide rich content, such as VR IMAX and VR gaming. The content of VR IMAXs comes from the traditional video platform, while any high-quality gaming content is rich. Therefore, the existing contents can be used to develop VR users.

- **The number of users is greater than 100,000.**
  There is room for imaginative business, which can drive content vendors to produce VR live contents such as concerts, variety shows, sporting events, and VR educational contents. In addition, copyright parties are interested in investing. During this phase, VR live broadcasting, VR education, VR IMAX, VR gaming, or VR 360 ° video scenarios can be selected to gain user loyalty.

3.1.2 Content Selection

Only abundant and high-quality content can maintain the sustainable development of Cloud VR services. Therefore, specific requirements are given to VR content based on user experience. For details, see the following table.

VR Content	Suggestions for Technical Parameters
VR IMAX	Resolution: 4K Typical bit rate: ≥ 20 Mbit/s (Note 1) Frame rate: 30/60 FPS Compression mode: VBR/CBR Video coding formats: H.264, HEVC, and AVS2
VR 360° video, VR live broadcasting, and VR education (Note 2)	Full-view resolution: 4K–8K Typical bit rate: ≥ 40 Mbit/s Frame rate: ≥ 30 FPS Video coding formats: H.264 and HEVC Degrees of freedom (DoF) for interaction: 3 DoF
VR gaming and VR education (heavily interactive) (Note 3)	Content resolution: 2K–4K (equivalent full-view: 4K–8K) Frame rate: 50–90 FPS Typical bit rate: ≥ 40 Mbit/s DoF for interactions: 6 DoF/3 DoF

Table 3-1 Suggestions for technical parameters of VR content

Note 1: The main content of VR IMAX is traditional video. To balance the bit rate of a large number of content sources on the existing network, the typical bit rate of VR IMAX is set to be greater than or equal to 20 Mbit/s.

Note 2: This type of VR education refers to video-based VR education, which focuses on viewing experience.

Note 3: This type of VR education is heavily interactive.

3.2 Assumptions of Content Operation and Business Models

3.2.1 Operation Cooperation

To develop Cloud VR services, operators must have in–depth cooperation with operation vendors, platform vendors, content providers, and terminal vendors. Figure 3–1 shows these relationships.

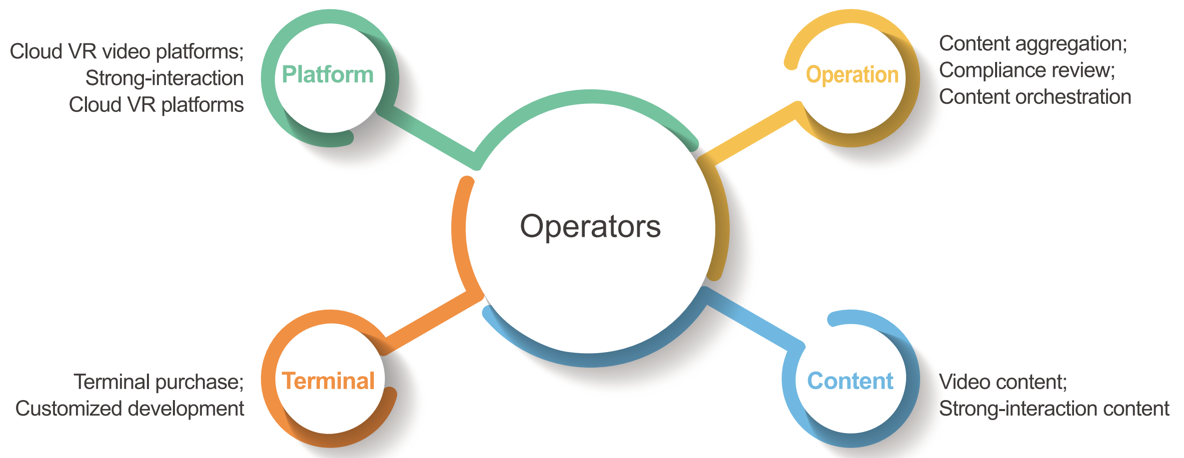

Figure 3-1 Relationship between operators and their partners

- **Platform vendors:** Assist operators to build VR service platform capabilities.
- **Operation vendors:** Cooperate with operators in the long term, including assisting operators with content aggregation, compliance reviews, and content coding.
- **Content providers:** Continuously provide VR videos and strong-interaction contents.
- **Terminal vendors:** Provide VR terminals and help terminal interconnection.

As Cloud VR is a new service, operators must pay attention to the following during service development:

- There are no strong regulatory policies for VR content. Operators must consider reviews of the subject and technical compliance of contents.
- The subject and technical compliance of content must be endorsed by a professional team with appropriate qualifications.
- Most VR content is produced by start-ups or studios, meaning their quality varies. Content aggregation and technical compliance reviews must be undertaken by a team with appropriate VR content review qualifications.
- The cloud rendering platform is required to introduce strong-interaction Cloud VR services. The introduction is undertaken by a team with cloud rendering capabilities.

3.2.2 Assumption of VR Service Packages

Based on the Internet business model, operators can ignore basic package fees, and adopt a business model of Free + Member + VOD products as follows:

- **Free content design**

  Operators can provide all registered users with a free design for less than 20% of the total content.

- **Member content design**

  In addition to charged VOD content, video, education, and gaming resources are open to all members.

- **VOD content design**

  VOD content is charged by number of times used. The content volume is updated based on content IP addresses. The main content is VR broadcasting, such as live concerts and sporting events.

3.3 VR Ecosystem

Operators must aggregate high-quality VR resources for developing Cloud VR services. Huawei's VR OpenLab industry cooperation plan aims to cooperate with industry partners, incubate business scenarios, promote technology and solution innovation, and build an open Cloud VR platform to promote prosperity in the industry. VR OpenLab has gathered more than 50 excellent industry partners, has a mature VR industry cooperation process, and can help operators smoothly deploy Cloud VR services.

VR Hardware Type	Major Vendors
VR HMD	VIVE, Oculus, Samsung, Pico, Skyworth VR, DPVR, 3Glasses, Huawei, iQIYI, Pimax, MI, and Idealens
Other peripherals	NOLO VR, LeapMotion, and uSens

Table 3-2 Major VR hardware vendors

VR Content Type	Major Vendors
Movie and TV	Felix & Paul Studios, Google Spotlight Stories, Jaunt VR, Pinta Studios, Sandman Studios, Letin VR, and iQIYI
Tourism	Letin VR, Whaley VR, ZANADU, CloudWave, Yunjing720, Shijieduomeili VR, and Escher VR
Live broadcasting	Letin VR, Whaley VR, iMatchic VR, Next VR, and True VR
Gaming	Niantic Labs, Three Eggs Studio, Survios, SEGA, Crytek, 7663 VR, Zamer VR, NetDragon Websoft, 9DVR, Kukr Digital, DY Magic, and Sureal
Education	Google Expeditions, zSpace, Immersive VR Education, Unimersiv, Alchemy VR, Discovery VR, NetDragon Websoft, Sail Before, Fly VR, HEIVR, 51VRCLASS, VRschool, ZONTEC, and Growlib
Healthcare	Firsthand Technology, Virtual Reality Medical Center, ImmersiveTouch, Surgical Theater, Touch Magic, and Invision
Shopping	Jingdong Tiangong Plan, Taobao Buy+, and Amazon

Table 3-3 Major VR content vendors

04 Expectations

The development of Cloud VR services is based on experience and is completed in three phases. These are the fair-experience phase, comfortable-experience phase, and ideal-experience phase.

4.1 Three Phases of Cloud VR Development

Fair-Experience Phase

In the fair-experience phase, typical content is 4K VR, and the typical resolution of terminals is 2K–4K, equivalent to that of 240P images seen on traditional TVs. VR video services focus on passively-accepted experience, support 3DoF interactions, and use the full-view transmission solution. Strong-interaction VR services focus on active-operation experience and support 6DoF/3DoF interaction. User interaction depends on handles.

Comfortable-Experience Phase

In the comfortable-experience phase, typical content is 8K VR, and the typical resolution of terminals is 4K–8K, equivalent to that of 480P images seen on traditional TVs. In addition, chip performance and ergonomic performance are improved. VR video services focus on passively-accepted experience. Any content that is more than 100 Mbit/s is applicable to FOV transmission. Strong-interaction VR services focus on active-operation experience, with interactive positioning being developed toward inside-out and handles integrated with hand gestures, and can identify complex scenarios and small objects while providing tactile feedback.

Ideal-Experience Phase

In the ideal-experience phase, typical content is 12K or 24K VR, and the typical resolution of terminals is 8K–16K. This development of terminals and contents enables users to enjoy an optimal experience, and allows users to become completely immersed in a virtual world. A good VR experience is based on strong social interaction, so it must be ensured that tactile feedback is maturely used.

4.2 Service Experience Indicators in the Three Phases of Cloud VR Development

Table 4-1 lists the different service indicators during the three phases of Cloud VR development based on research and algorithm inferences.

Service Type	Service Indicator	Fair-Experience Phase	Comfort-Experience Phase	Ideal-Experience Phase
Terminal	Display resolution	2K–4K	4K–8K	8K–16K
Strong-interaction Cloud VR service	Content resolution (Equivalent full-view resolution)	2K–4K (Equivalent full-view: 4K–8K)	4K–8K (Equivalent full-view: 8K–12K)	8K–16K (Equivalent full-view: 12K–24K)
	Color depth (bit)	8	8	12
	Coding format	H.264/H.265	H.265	H.265/H.266
	Bit rate (Mbit/s)	≥ 40	≥ 90	≥ 360/440 (12K/24K)
	FOV (degree)	90–110	120	120–140

	Frame rate (FPS)	50	90	120–200
	Operation response delay (ms)	≤ 100	≤ 100	≤ 100
	MTP	≤ 20	≤ 20	≤ 20
	Valid frame rate	100%	100%	100%
Cloud VR video service	Full-view resolution	4K–8K	8K–12K	12K–24K
	Color depth (bit)	8	8	12
	Coding format	H.264/H.265	H.265	H.265/H.266
	Bit rate (Mbit/s)	≥ 40	≥ 90 (full view) ≥ 50 (FOV)	≥ 290/1090 (full-view: 12K/24K) ≥ 155/580 (FOV: 12K/24K)
	FOV (degree)	90~110	120	120~140
	Frames per second (FPS)	30	30	60~120
	Operation response delay (ms)	≤100	≤100	≤100
	Initial buffer duration (s)	≤1	≤1	≤1
	Proportion of duration with freezing	0	0	0
	Proportion of duration with a blurry display	0	0	0

Table 4-1 Service indicators for the three development phases of Cloud VR

4.3 Expected Latency Requirements of the Cloud VR Solution

For VR video services, a latency of 20 to 40 ms can meet user experience requirements. The latency requirement of strong-interaction VR services will be the highest found in the Cloud VR solution. Latency is expected to follow the three development phases:

1. The MTP latency less than or equal to 20 ms.

2. The latency for cloud rendering and streaming ranges from 30 to 70 ms.

- At the entry-level phase, latency of less than or equal to 70 ms is acceptable for cloud rendering and streaming. Black edges and quality deterioration are also acceptable. (The solution described in this white paper meets this requirement.)

- At the comfortable-experience phase, latency of less than or equal to 50 ms is acceptable for cloud rendering and streaming. In this case, black edges are almost eliminated.

- At the ideal-experience phase, latency of less than or equal to 30 ms is acceptable for cloud rendering and streaming. No black edge or image distortion will occur.

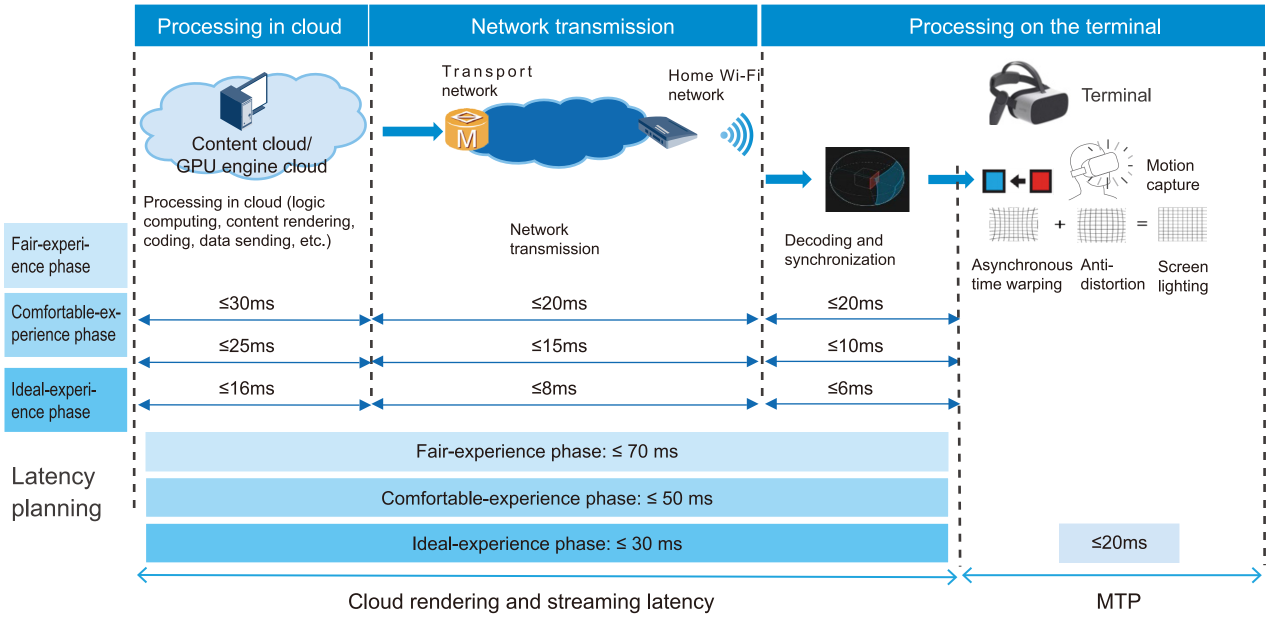

Figure 4-1 Latency requirements for each development phase of Cloud VR

4.4 Expected Network Requirements of the Cloud VR Solution

Table 4-2 lists the network requirements at the three development phases of Cloud VR services based on service experience indicators.

Phase		Fair-Experience Phase	Comfort-Experience Phase	Ideal-Experience Phase
Cloud VR video service	Bandwidth	≥60Mbit/s	Full view: ≥140Mbit/s FOV: ≥75Mbit/s	Full view: ≥440Mbit/s (12K) ≥ 1.6Gbit/s (24K) FOV: ≥230 Mbit/s (12K) ≥ 870Mbit/s (24K)
	RTT (Note 1)	≤20ms	≤20ms	≤20ms
	Packet loss rate	9E-5	1.7E-5	1.7E-6
Strong-interaction Cloud VR service	Bandwidth	≥80Mbit/s	≥260Mbit/s	≥1Gbit/s (12K) ≥1.5Gbit/s (24K)
	RTT	≤20ms	≤15ms	≤8ms
	Packet loss rate	1.00E-5	1.00E-5	1.00E-6

Table 4-2 Network requirements for each development phase of Cloud VR

Note 1: VR video services do not require the network RTT to be less than 20 ms. However, a smaller RTT means a shorter image loading time during channel switching and video playback. If the loading time is not important, an RTT of 30 ms to 40 ms is acceptable.

4.5 Expectations of the Cloud VR Solution

In the future, the Cloud VR solution will be improved in the following ways:

1. Terminal

Terminals develop fast, especially those in the consumer market. The decoding capabilities of terminals will reach 8K, the field of view will develop towards 120 ° , eye protection modes will emerge, terminals will become lighter, and price will further be optimized.

2. Network transport

Fixed transport network: Home Wi-Fi will be upgraded to a rate higher than 1 Gbit/s. 5 GHz Wi-Fi will be upgraded to 802.11ax or 60 GHz Wi-Fi, and 25G PON and one-hop WDM transmission will be used. With improvements to VR image quality, home network bandwidth will increase from 100 Mbit/s or 200 Mbit/s to 300 Mbit/s and beyond.

5G wireless transmission network: On June 14, 2018, 3GPP officially approved the freezing of the 5G NR SA function. This milestone event will pave the way for the trial and commercial use of 5G networks. 5G networks can provide 100 Mbit /s bandwidth anytime and anywhere, meeting requirements for 4K VR resolution or higher HD quality experience. Meanwhile, network latency of just 5 to 8 ms will eliminate dizziness.

3. VR video service platform

With the bandwidth of VR video services exceeding 100 Mbit/s, the transmission solution has developed to FOV transmission, such as TWS transmission. In addition, VR live broadcast services are gradually adopting the multicast solution to reduce network load.

4. Strong-interaction VR service platform

In addition to continuously improving the consistency between the Cloud VR experience and the local VR experience, it is critical that E2E latency is reduced and cloud rendering processing performance is improved. This can be achieved by taking measures such as cloud rendering resource pooling, on-demand elastic allocation of GPUs and CPUs, encoding performance improvements, and using ultra-fast transmission protocols.

5. Content aggregation platform

As terminals start providing 8K decoding capabilities, ever-more content will boast 8K resolution. After operators launch VR services to the home market, content providers must keep up in terms of the capabilities and quantity of high-quality VR content. This will ensure more VR users are attracted and retained.

A Acronyms and Abbreviations

Acronym and Abbreviation	Full Spelling
AP	Access point
APK	Android package
BRAS	Broadband remote access server
BNG	Broadband network gateway
CBR	Constant bit rate
CDN	Content delivery network
CO	Central office
CPU	Central processing unit
CR	Core router
CSMA/CA	Carrier sense multiple access-collision avoidance
DAA	Destination address accounting
DLNA	Digital Living Network Alliance
DoF	Degrees of freedom
DSCP	Differentiated services code point
FTTB	Fiber to the building
FTTC	Fiber to the curb
FTTH	Fiber to the home
FOV	Field of view
GPU	Graphics processing unit
HGW	Home gateway
HQoS	Hierarchical quality of service
MDN	Media delivery network
MTP	Motion to phot

Acronym and Abbreviation	Full Spelling
MIMO	Multiple input multiple output
MU-MIMO	Multi user multiple input multiple output
ONT	Optical network terminal
OFDM	Orthogonal frequency division multiplexing
OLT	Optical line terminal
OTN	Optical transport network
OTT	Over the top
PON	Passive optical network
PPD	Pixels per degree
QoS	Quality of service
RET	Retransmission
RTSP	Real time streaming protocol
RTP	Real-time transport protocol
RTT	Round trip time
SDK	Software development kit
STB	Set top box
TCP	Transmission control protocol
UDP	User datagram protocol
VBR	Variable bit rate
VR	Virtual reality
WMM	Wi-Fi multimedia

HUAWEI TECHNOLOGIES CO., LTD.
Bantian, Longgang District
Shenzhen518129, P. R. China
Tel:+86-755-28780808

www.huawei.com