# Design of Virtual Reality Education Platform based on 5G MEC

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**Abstract—The commercial construction of 5G communication networks has brought new technological development opportunities for virtual reality education. Virtual reality education is a typical scenario of large bandwidth service, which brings huge pressure to the traditional network architecture. The multiple access edge computing (MEC) can bring the user panel closer to the terminal, and fulfill the requirements of short loop VR flow transmission, ultra low delay and real time rendering. By investigating the in-depth integration of MEC and virtual reality education scenario, the MEC network architecture and the deployment of virtual reality education platform based on 5G MEC are introduced in details. Then the test result based on the real 5G MEC network environment is analyzed.**

***Keywords-5G, MEC, Virtual Reality Education, Cloud Rendering***

## I. . INTRODUCTION

Virtual reality technology has entered a new stage with the development of 5G. According to Goldman Sachs report [1], the VR/AR market worldwide is estimated to reach 80 billion U.S. dollars by 2025. Education is one of the nine industries which are expected to be successful in VR/AR field. Global Internet giants have increased their investments in VR/AR business in recent years. Facebook has acquired Oculus VR business as early as 2014 and recently announced the "Metaverse" plan [2]. Microsoft has its own VR/AR terminals "HoloLens" and application platform, namely "Dynamics 365 mixed reality applications" and "Windows Mixed Reality". Google has also launched the "Google Expeditions plan" to provide the public with the virtual reality education services.

Education is one of the main directions of the virtual reality industries. In education scenarios, virtual reality technology provides students with an immersive learning experience by visualizing abstract learning content. VR education can provide intelligent interactions capabilities, which makes the learning experience to be more lively and vividly. The new immersive teaching and learning mode with the characteristics (e.g., openness, interaction, collaboration) is welcomed by students. Virtual reality education has become the most important component of smart education.

Virtual reality requires the network to provide large bandwidth and low transmission delay. Traditionally, servers are usually deployed locally to reduce network transmission delay and improve user experience. With the increasing demand for multi-person interaction and cooperation, cloud-based virtual reality is the current research hot-spot. Due to the strong interaction characteristics of virtual reality, cloud VR flow poses a very high challenge to the network transmission, requiring ultra-large uplink bandwidth, and ultra-low delay. 5G eMBB and uRLLC features can just match the needs. When VR graphic rendering is mentioned, real-time graphic processing is always the tough issue to be handled. MEC can help to sink down the user panel and reduce network latency. With the help of edge computing, graphic rendering can be processed closer to user, and VR contents can be managed in the cloud.

This paper studies the combination of MEC and virtual reality education scenarios, introduces the MEC architecture and virtual reality education platform. Then, this paper explains the deployment method based on 5G MEC, and analyzes the test result in real 5G network environment.

The rest of this paper is organized as follows: Section II analyzes the current situation of virtual reality education. Section II also introduces the global virtual reality education policy, the application scenarios, pain points, and VR education network requirements. Section III introduces the MEC deployment method of the virtual reality education cloud platform, and analyzes the test result based on real 5G MEC network. Section IV concludes the whole paper.

## II. ANALYSIS OF VIRTUAL REALITY EDUCATION DEVELOPMENT STATUS

### A. *Virtual Reality Education Policy*

Many countries pay great attentions to the development of virtual reality education and have announced relative policies in recent years.

In 2013, the U.S. government released the first Federal Government's five-year Strategic plan for STEM education. In 2016, the Department of Education in US released "STEM 2026: A vision for innovation in STEM Education". In 2018, "North Star" as the next five-year strategic plan for STEM education was released, which focused on promoting high-quality STEM and computer science together to simulate the virtual reality experiences.

The German Ministry of Education BMBF supported the virtual reality technology to be used in vocational education field. In 2018, BMBF issued the "Virtual and Augmented Reality (VR/AR) in Vocational Education and Training" project guide. In 2019, BMBF released the "Digital

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Transformation 4.0 Plan", aiming to improve vocational skills by digital education.

Australia government launched the "National STEM School Education Strategy 2016-2026". In the "National Innovation and Science Agenda", Australia government proposed the implementation of the "Inspiring all Australians in Digital Literacy and STEM Package Plan", to help students embrace the digital era.

Chinese government successively issued a series of policies to encourage virtual simulation experiment projects and steam projects. "Education Informatization 2.0", clearly emphasized the construction of a smart learning support environment. In the "14th Five-Year Plan", VR/AR was mentioned as the Key industry of the digital economy.

### *B. Virtual Reality Education Scenario Description*

Virtual reality education has a wide range of requirements, for example, the K12 (Kids under 12 years old), higher education, vocational education, and pan-education. The application of virtual reality education has evolved from the pilot stage to comprehensive developing stage.

For elementary and middle school education, the United States, Australia, and the United Kingdom have tried to launch STEAM/STEM projects. For higher education, virtual simulation laboratory projects have been carried out by a number of top universities such as Stanford University, the University of California, Berkeley, etc. The virtual laboratory of Stanford University provides students with a situational practical training environment for learning financial market knowledge. The University of California, Berkeley, has created a virtual simulation laboratory for the large-scale open online course (MOOC) of cyber-physical systems. Germany combines virtual reality vocational education with Industry 4.0 to enhance practical training capabilities. In the field of pan-education field, virtual reality education has been used in the aesthetic education, sports education, etc.

### *C. Virtual Reality Education Pain Points*

The limitations of virtual reality education are mainly in two aspects, the shortage of qualified virtual reality education contents and the immaturity of VR technology itself.

The shortage of virtual reality education content is mainly due to the high price of qualified VR content and the resource sharing problem. Traditional virtual reality education products are normally deployed and used locally. While on the contrary, in education scenario, multiple students need to participate and coordinate in one virtual simulation experiment. Considering the real requirement, it is quite necessary to break the chimney of vertical silo at the current status. A cloud-based virtual reality education platform solution is expected to solve the problems of resource sharing and collaborative operation.

Meanwhile, the virtual reality technology itself still has some shortcomings, such as the discomfort caused by the weight of the head-mounted device, and the Cybersickness caused by the delay of the head movement response and insufficient resolution. The lightweight head-mounted terminal without the data transmission line has limited storage and limited local processing capabilities. 4K all-in-one VR terminal is quite expensive, and not suitable for the education scenario considering the cost [3]. Virtual reality technology has strict requirements for real-time network transmission, short latency and ultra-high bandwidth. VR video and audio real-time calculations require complex calculations and processing capabilities, especially about the graphics processing, real time rendering, etc. The realization of the complicated calculation in the current network with lightweight VR headset is still a challenge, edge cloud technology is proposed to reduce the transmission latency.

### *D. Analysis of Network Requirements for Virtual Reality Education Cloud Platform*

VR experience has three notable characteristics, namely "Immersion", "Interaction", "Imagination". The resolution, color depth, response speed, are the key factors to affect the experience of VR education correspondingly.

For the network aspect, the architecture of virtual reality education cloud platform consists of multiple layers, including cloud/edge layer, network layer and the terminal layer. Cloud and edge cooperate together to complete the real-time encoding, decoding and content rendering of VR stream. For the network layer, VR flow requires network transmission with ultra high bandwidth, no jams, and ultra low latency for both uplink and downlink [4]. For the terminal layer, the platform takes human-computer interaction, asynchronous distortion, and anti-distortion processing to improve the user terminal perception. There are three network indicators, namely bandwidth, network delay, packet loss rate, which are the most important factors to affect to user experience in VR education scenario.

In terms of bandwidth, 4K panoramic VR flow requires about 80Mbps-120Mbps. In the education scenario, the number of VR terminals in the classroom should also be considered. Taking 50 students as an example, the uplink bandwidth is about 6000Mbps. In terms of network delay, it is generally believed that the virtual reality interaction delay should be about 20ms, otherwise it will bring a sense of dizziness to the user. Therefore, the total time delay including the network transmission, cloud rendering, and logic calculation should be less than 20ms, and for comfortable experience, the time delay will be further required to be less than 15ms [5]. Stuttering will directly affect the user perception, and correspondingly, the packet loss rate should be controlled in a stringent range.

## III. Virtual Reality Education Platform MEC Deployment Method

Combining with 5G MEC technology [6-8], the virtual reality education cloud platform provides GPU rendering capabilities for the application layer through setting user panel down to the user by MEC deployment, which can effectively reduce the rendering time in virtual reality education scenarios and improve user experience. Qualified educational resources are stored and managed uniformly in the cloud, no longer necessary for users to download and store them locally, which could guarantee the copyright protection of the content. Hardware resources can be configured and used more flexibly and effectively with the help of cloud rendering technology.

*A. MEC Architecture and Features*

Combing CT's connection capability and IT computing capability, MEC empowers the vertical industry services, providing strong low-latency edge computing capabilities, and enabling 5G technology deeply penetrating to multiple applications scenarios. Cloud, network, edge, terminal and industry applications are deeply integrated to provide users with truly valuable applications with the MEC services.

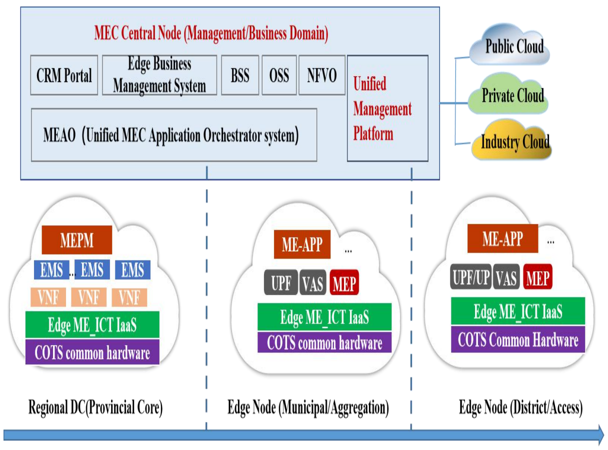


Fig. 1. Telecom operator's MEC overall architecture

In terms of deployment architecture, MEC edge cloud consists of MEC central node, regional/provincial core node, municipal/aggregation node, and district/access node. The central node includes several important functions, such as OSS (Operation Support System), BSS (Business Support System), CRM Portal (Customer Relationship Management), NFVO (Network Functions Virtualization Orchestrator), Unified Management Platform, and MEAO (Multi-Access Edge-Computing Application Orchestrator), which provides open interfaces and takes the role of orchestration and management of edge business applications of the entire network. The regional/provincial node is the core of the MEC business. Network elements such as MEPM (Multi-access Edge Computing Platform Manager) and MEP (Multi-access Edge Computing Platform) will be deployed to provide ME_ICT-IaaS (Multi-access Edge Computing Information Communication Technology-infrastructure as a Service), virtualized resource management, MEP access collaboration platform, node business management and other functions to provide customers with centralized services. The municipal/aggregation node is responsible for the deployment of ME-APP (Multi-Access Edge-Computing Applications), ME_ICT-IaaS, MEP, ME-VAS (Multi-access Edge Computing Value Added Service), and to support customers' specific business applications. The district/access node is deployed for customers' exclusive services on demand [9].

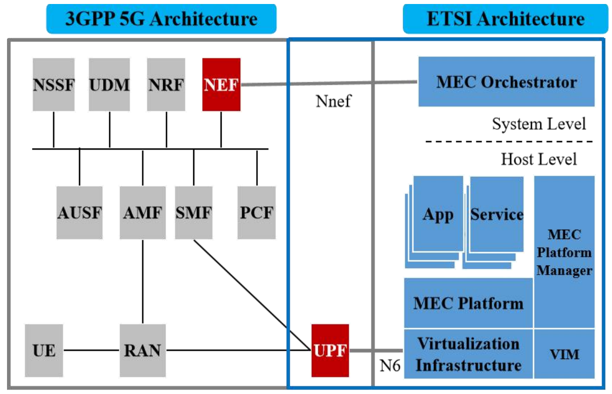


Fig. 2. GPP & ETSI 5G MEC architecture

MEC is the extension of the distributed gateway UPF (User Plane Function), and the expansion of the business platform at the same time, which realizes the true integration of ICT capabilities. 3GPP defines a network architecture with C/U separation, UPF is the data anchor point for edge computing. ETSI defines the business framework of MEC, including software architecture, application scenarios and API interfaces. UPF is the key point for the integration of ETSI and 3GPP network architecture. In the core network layer, CU is separated, and the U plane can be deployed flexibly on demand. The core network supports three traffic offloading mechanisms to meet the offloading requirements in different scenarios. Multiple service continuity mechanism is designed to guarantee the continuity requirements of different services. Dynamic interaction mechanism is proposed to support UPF to add and delete applications locally on demand. Fig. 2 shows the combination of 3GPP & ETSI about the 5G MEC architecture [10][11].

*B. Virtual Reality Education Platform Architecture*

The virtual reality education cloud platform combines cloud computing and cloud rendering capabilities with 5G MEC. Through Cloud Virtual Reality (Cloud VR), the interactive signals from the user side are uploaded to MEC, and MEC completes complex calculations and image rendering and carries out the encoding/decoding calculation functions. The VR audio/video streams are compressed and converted, after rendering by MEC, the compressed VR flows are transmitted to the user's VR terminal through the 5G network [12]-[14]. The requirements for the head mounted terminals are reduced, costs are saved, which greatly reduces the threshold for VR applications, and improves user experience. Meanwhile, the contents are unified managed by the cloud platform and thus facilitating copyright protection. The unified platform also provides convenient for further integration and resource sharing of qualified virtual reality education materials.

The architecture of the virtual reality education cloud platform is divided into four layers: content layer, platform layer, network layer, and terminal layer, as shown in Fig. 3.

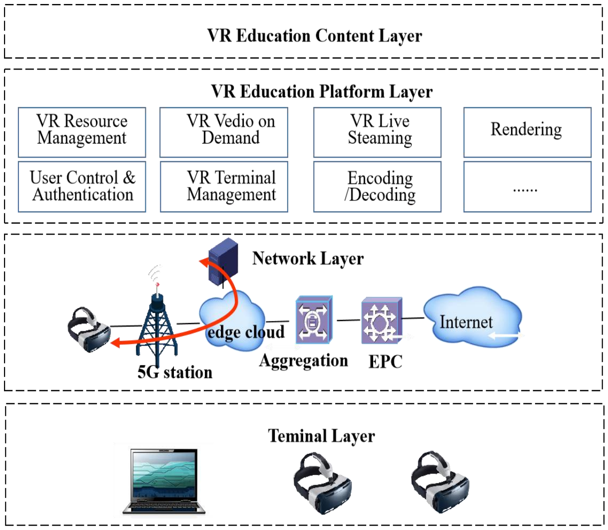


Fig. 3. Virtual reality education platform architecture

The content layer integrates qualified virtual reality teaching resources. The platform layer provides unified authentication for users, completes content synchronization with the content layer, and realizes dynamic interactive capabilities, such as VR live broadcast, VR on-demand, encoding/decoding, real-time rendering and other platform capabilities. The network layer implements local traffic offloading function through the edge cloud, realizes real-time rendering to reduce the latency, and improves user experience. The terminal layer includes a variety of head mounted terminals and interactive devices, providing UI interface, which is convenient for users to operate.

### C .MEC Virtual Reality Education Platform Deployment Method

MEC provides cloud computing capabilities and IT service capabilities for the virtual reality education cloud platform. MEC makes the cloud computing and cloud storage closer to the user. This provides a carrier-class service environment with high performance, low latency and high bandwidth, and accelerate the distribution and knowledge sharing of virtual reality education content through the network.

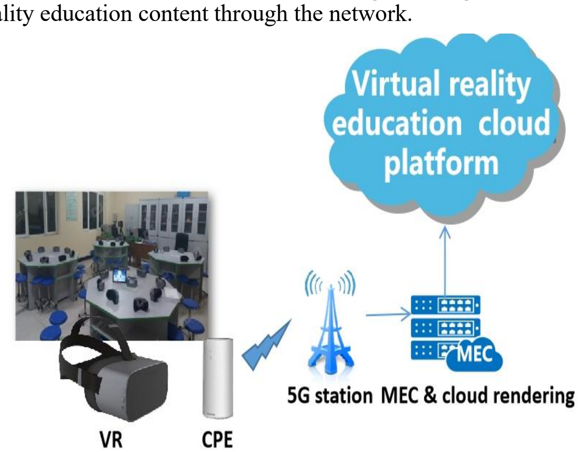


Fig. 4. Virtual reality education network topology

The virtual reality education cloud platform combines 5G MEC edge with real-time cloud rendering technology, ultra-low latency interactive streaming technology. The low-cost edge cloud deployment solution is aiming to provide virtual simulation resources which can be accessed anytime, anywhere, and thus to improve the convenience of Virtual reality education resource sharing, realize centralized management of users, multi terminal access and efficient maintenance and operation [15]-[17].

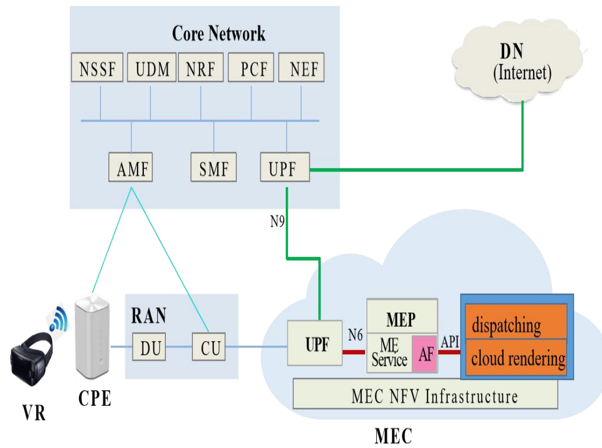


Fig. 5. MEC virtual reality education deployment diagram

The virtual reality education cloud platform deployment mainly contains three parts, virtual reality education cloud platform, MEC edge service, and VR terminal. The virtual reality education cloud platform is deployed in the cloud and is responsible for user login, content management, and content distribution. The MEC edge service is mainly providing functions such as scheduling, real-time rendering, encoding/decoding, and local resource management. Edge scheduling mainly implements functions such as content storage, scheduling rendering tasks, and user authentication. Edge cloud rendering platform provides users with cloud rendering and computing services, which is one of the most important factors to improve the VR user experiences. Real-time encoding and decoding are used to process VR audio and video streams, local resource management is used to store resources in MEC resource pool. The VR terminal includes various types, such as VR headsets, AR devices, MR glasses.

The virtual reality education central cloud platform is connected with the MEC edge to synchronize the contents. The cloud rendering platform can be deployed on MEC in different physical locations and in multiple ways (e.g., on the core network side, on the 5G base station side, and inside campus as a server). MEC helps to provide the strong GPU rendering and CPU computing capabilities closer to the user, the processed real-time audio and video streams will be transmitted to the VR terminal with short transmission loop. The VR terminal sends back the user's control signal to the MEC edge cloud, and interacts with the cloud rendering platform based on the 5G network [18]-[21]. With the help of 5G MEC edge computing capabilities, flexible scheduling and agile deployment of computing resources can be realized. The collaboration of multiple technologies of the cloud, network, edge, and the end, has greatly improved user experience of the virtual reality education [22]-[25].

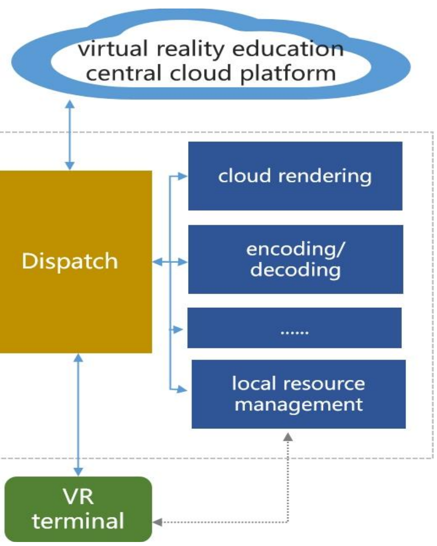


Fig 6. Virtual reality deployment diagram

VR flow rendering process under the MEC environment is shown as Fig.7.

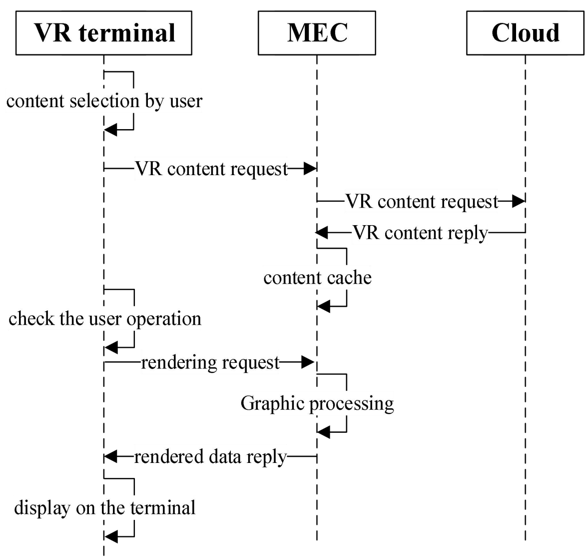


Fig 7 Data flow of the rendering process

When the user selects the VR content, MEC first makes a content request to the cloud and caches the VR content in the edge server. User operation will be monitored in real time, with the user movement, rendering request will be sent from the VR terminal to the MEC server. MEC carries on the graphic processing, and the rendered result will be sent back to the VR terminal.

Imagine that if the VR terminal directly initiates a processing request to the cloud, every tiny movement of the user will be handled by the cloud, which will cause high transmission pressure to the network and high calculation pressure on cloud.

The MEC and the cloud platform cooperate together, image rendering will be processed by MEC, and the content management will be done by the cloud, which effectively solves the problem of time delay and resource sharing.

In the field of MEC computing offloading, computing offloading decision-making, computing resource allocation and mobility management are normally regarded as the most important parts [26]-[29]. In virtual reality education field, real-time image rendering and real-time encoding and decoding require huge amount of GPU/CPU resources. The MEC deployment of the virtual reality education cloud platform is mainly to offload the complicated real-time rendering calculation and encoding/decoding calculation from the VR terminal to the MEC server. In this process, edge computing service overhead and network delay are the most important issues to be considered [30]-[32].

The calculation indicators of time delay are as follows: We suppose that the computing resource required to complete a certain computing task is $m$, and the local execution speed is $v_{local}$. The time required for local execution is (1):

$$t_{local} = \frac{m}{v_{local}} \tag{1}$$

We suppose the network bandwidth is $B$, the current calculation task size is $b_i$, the MEC calculation speed is $v_{MEC}$, then the time required for offloading to MEC execution is (2):

$$t_{MEC} = \frac{b_i}{B} + \frac{m}{v_{MEC}} \tag{2}$$

If $t_{mec} < t_{local}$, there is (3):

$$\frac{m}{v_{local}} - \frac{m}{v_{MEC}} < \frac{b_i}{B} \tag{3}$$

In the actual 5G MEC deployment process, the user experience of the VR education is most sensitive to the overall delay. The real-time rendering calculation by the MEC closed to the user side will effectively reduce the time latency.

### D. Analysis of MEC Deployment Test Results

In the real 5G network environment, the virtual reality education cloud platform was deployed and verified based on MEC. Image-based rendering server was deployed on MEC, and the forwarding rules were configured correspondingly. Virtual machine was configured to support the cloud rendering function. Tests with two VR and four VR terminals were made separately, and each VR terminal was corresponding to a GPU card. VR terminals were connected to 5G TUE via WiFi. Server configuration for the test environment was shown in Table.1, NVIDIA GeForce GTX 1080 was used as the GPU, and TP-LINK AC1300 was used as the router in this test.

TABLE 1 SERVER CONFIGURATION OF THE TEST ENVIRONMENT

| Items | Description | Number |
|---|---|---|

| | | |
|---|---|---|
| Hardware platform | Micro workstation 7048GR-TR | 1 |
| Processor | Intel Xeon E5 2667 V3（3.2HZ cores） | 2 |
| Memory | SAMSUNG ECC DDR4 16G 2400 | 4 |
| Hard disk | Intel S4610 480G | 4 |
| GPU | NVIDIA GeForce GTX 1080 | 4 |

The test topology environment with two VR terminals and four VR terminals were shown in Fig.8 and Fig.9.

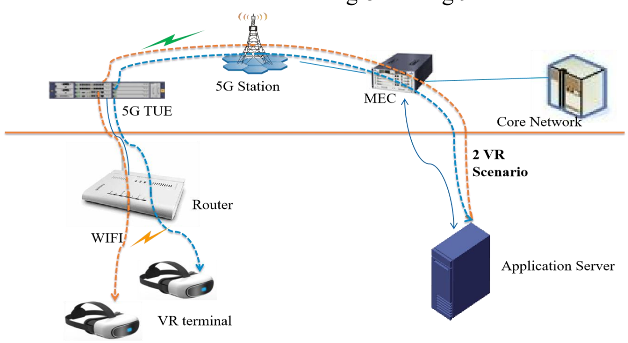


Fig. 8. Test topology environment with two VR terminals

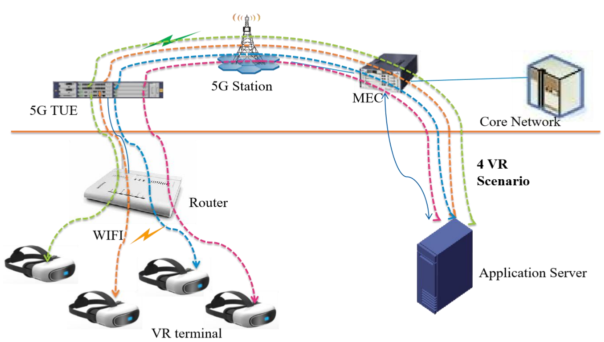


Fig. 9. Test topology environment with four VR terminals

The MEC cloud rendering test was carried out, after rendering by MEC, the VR education content was transmitted to the VR terminal. The VR video flow was decoded and displayed on the VR terminal by the built-in decoding algorithm. The test results were shown in Table.2.

TABLE 2 TEST RESULTS BASED ON 5G MEC WITH DIFFERENT NUMBERS OF VR TERMINALS

| **Performance Indicator** | **Test Results** | |
|---|---|---|
| Device Number | 2 VR terminals | 4 VR terminals |
| TotalPackets | 284611 Packets | 600669 Packets |
| PacketRate | 3234 Packets | 2955 Packets |
| PacketsLostTotal | 2 Packets | 0 Packets |
| PacketsLostInSecond | 0 Packets/s | 0 Packets/s |
| TotalSent | 386 MB | 813 MB |
| SentRate | 35.2 Mbps | 32.0 Mbps |
| TotalRate | 23.1 ms | 30.8 ms |
| TotalLatency | 11.9 ms | 14.3 ms |
| DecodeLatency | 11.2 ms | 16.4 ms |
| FecPercentage | 5% | 5% |
| FecFailureTotal | 0 Packets | 0 Packets |
| FecFailureInSecond | 0 Packets/s | 0 Packets/s |

Cloud rendering was completed on the MEC server side, the test results showed that the deployment based on the MEC environment could meet the delay requirements. For the two VR terminals scenarios, the total latency was about 23.1ms, the transport latency was 11.9ms, and the decoding delay was 11.2ms, the VR video and audio stream was about 100Mbps. For the four VR terminals scenarios, the total latency was about 30.8ms, the transport latency was 14.3ms, the VR video and audio stream was about 190Mbps. The latency was increased when the device number changed from 2 to 4. The image resolution was 2560×1440. For each test, there was no mosaic, and the VR terminals worked well and did not affect each other. At the same time, the user's subjective perception was good.

During the experiment, packet loss in the transmission section between the router and the VR terminal was monitored. After analysis the ping package, this was caused by unstable WIFI signal. We can expect that, when the VR terminal can be embedded with 5G module and directly connected to the 5G base station, it can effectively reduce the impact of WIFI instability and improve the performance.


Fig. 10. Resource management UI

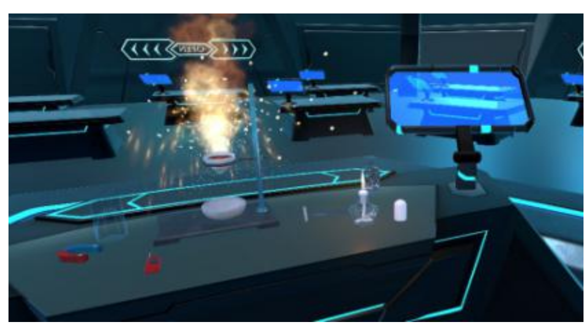

Fig. 11. VR headset UI (chemical lesson)

The resource management platform UI and the VR headset UI were shown in Fig.10 and Fig.11.

## IV. CONCLUSION

In this paper, we discuss the combination of 5G MEC technology and the virtual reality education application scenarios, deeply analyzes the MEC architecture, and gives the MEC deployment method of the virtual reality education platform. The combination of MEC and cloud rendering can effectively shorten the transmission path of VR flow through localized MEC services, which alleviates the pressure of network transmission bearer. The proposed virtual reality education cloud platform deployed on the 5G MEC combines the advantages of 5G MEC technology and the cloud rendering technology. This can reduce the weight of the VR headset, lower the price, and bring a better user experience, and thus to make the lightweight of VR headset come true. With the acceleration of 5G commercial deployment, the 5G MEC virtual reality education cloud platform has become a promising solution and has potential development prospects. In our future works, we will apply the deep learning algorithm with 5G MEC environment to reduce the VR flow processing time. In addition, we will also try human-machine interaction scheme to improve the user experience.

## ACKNOWLEDGMENT

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