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Carrier Grade Minimalist Multicast CENI Networking Test Report

Purple Mountain Laboratories for Network Communication and Security

Huawei Network Technology Laboratory

Jiangsu Future Networks Innovation Institute

Beijing University of Posts and Telecommunications

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Academician's Message

In the past half century, the TCP/IP network protocol system and data communication technologies have achieved great success, bringing human beings into the era of network informatization. Network technologies have become one of the driven forces for human civilization progress. Over the past 20 years, the rapid development of informatization technologies and the extensive construction of network infrastructure have provided a powerful driving force for China's economic development, facilitated people's communication and life, and brought people closer. Expectedly, network technologies will continue to develop rapidly and play a more extensive and important role in social production activities. We sincerely welcome more participants in developing network technologies and promoting human knowledge advancement.

Liu Yunjie

Academician of Chinese Academy of Engineering

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1 Multicast Technology Evolution for Carrier Grade Large-Scale Networks

TCP/IP technology, which started in 1969, has achieved great success in both development and global deployment over the past decades. In the TCP/IP protocol system, the multicast technology is an indispensable part. Since the introduction of multicast in 1988, many international standards organizations have done a lot of work on the research of multicast technologies and the development of multicast services. The multicast protocol suite is classified into multicast management protocols (used between multicast hosts and access network devices) and multicast routing protocols (used between multicast forwarding network devices). Multicast management protocols establish relationships between network devices and multicast group members (recording information about multicast network access of multicast group members) and manage joining and leaving of multicast group members. As a multicast management protocol, Internet Group Management Protocol (IGMP) has three versions: IGMPv1, IGMPv2, and IGMPv3. In addition to the processing of joining and leaving of multicast group members, IGMP defines functions such as multicast group member query and report and specifying the multicast sources from which data is to be accepted. Multicast routing protocols use certain multicast routing algorithms to construct multicast distribution trees (MDTs) according to multicast group membership information, and establish multicast routing states on network devices. The network devices then forward multicast data packets according to these states. Typical multicast routing protocols include Protocol Independent Multicast Dense Mode (PIM-DM) and Protocol Independent Multicast Sparse Mode (PIM-SM), which use Join/Prune messages to construct MDTs in scenarios where multicast members are densely distributed and in scenarios where multicast members are sparsely distributed, respectively. PIM-DM and PIM-SIM need to establish an MDT for each multicast flow so that multicast traffic can be replicated along a specific tree-shaped multicast path. In this case, a network device needs to maintain forwarding entries of multiple multicast groups. When a large number of multicast groups exist, consumption of entry resources, which are expensive, poses a great challenge to the network device. In addition, MDT establishment depends on the underlying routing protocol. As the multicast source cannot specify the forwarding path for a specified multicast flow, services such as Traffic Engineering (TE) and Quality of Service (QoS), which are forwarding path-based, cannot be implemented.

To overcome the drawbacks of traditional multicast, the Bit Index Explicit Replication (BIER) technology has been proposed in recent years. With BIER, the root node encapsulates a BitString in the packet header, and each bit in the BitString represents a leaf node (receiver node) rather than a transit node. Each node creates a bit index forwarding table (BIFT) to guide the forwarding of multicast packets encapsulated with the BitString. In this way, the entire underlay network shares one forwarding path, and there is no need to maintain a set of forwarding entries for each multicast group or multicast flow states. This reduces resource consumption and supports large-scale multicast services. Tree Segment Identifier (SID) is a solution for constructing MDTs based on Segment Routing. Based on the Path Computation Element Protocol (PCEP), the Tree SID solution uses the Segment Routing controller to calculate MDTs, allocate a tree SID to each forwarding node, and deliver the tree SIDs to related nodes to complete multicast policy deployment. In this manner, multicast traffic can be forwarded along a specified path, meeting TE capability requirements to some extent.

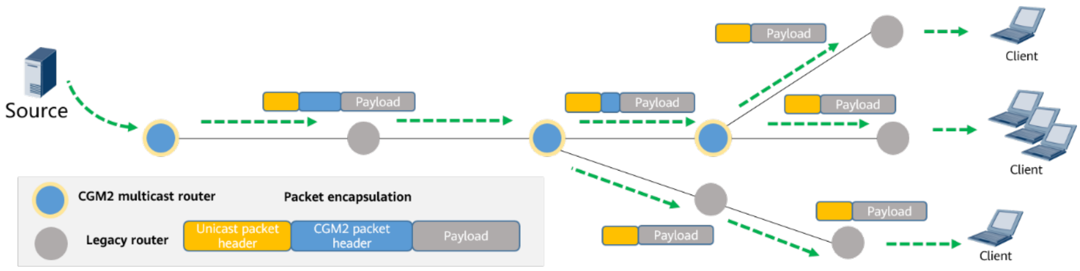
Existing multicast technologies, including stateful and stateless network-layer multicast technologies and application-layer multicast technologies, have some key technical issues and face the following challenges in carrier grade deployment:

- Stateful network-layer multicast technologies (such as PIM-DM and PIM-SIM) require network nodes to maintain a large number of multicast protocol states and multicast forwarding entries, consuming a large number of resources. When a fault occurs on the network, unicast routes converge before multicast routes do. As a result, E2E service convergence is slow, which cannot meet carrier grade requirements for fast convergence upon faults. When the network topology is large and there are many hops, new users cannot quickly join multicast groups, and the requirement for low-delay multicast group management cannot be met.

- Stateless network-layer multicast technologies (such as BIER) are stateless. However, in large-scale sparse multicast scenarios, BIER multicast is prone to degrade to unicast, which cannot reflect the traffic saving advantage of multicast. In addition, path planning is not supported. In scenarios such as traffic optimization and rerouting, path control technologies such as MPLS, SR, and Tree SID are required. Furthermore, the routing entry to the BIER node corresponding to each bit still needs to be maintained. On a large-scale network, the number of entries is still large.

Therefore, a new multicast technology — Carrier Grade Minimalist Multicast (CGM2), is brought up to meet the key requirements of carrier grade multicast deployment, including stateless forwarding, multicast path planning, SLA guarantee, high-performance forwarding, fast rerouting upon faults, and incremental deployment on legacy networks.

Figure 1-1 Vision of CGM2



The following table lists the key requirements of CGM2 and the corresponding technologies that can be implemented.

Table 1-1 Key requirements and construction techniques of CGM2

Target Feature	Technique Construction
Stateless forwarding	Forwarding entries are no longer maintained for each multicast group. Multicast source routing can be implemented based on the localized semantic bitmap. Devices maintain only neighbor-level entries and status, improving scalability.
Multicast path planning and SLA guarantee	Source Routing can be used to specify the forwarding path of multicast traffic and perform forwarding path constraints on per multicast traffic packet basis to implement traffic engineering and bandwidth reservation, ensuring the SLA of multicast services and user experience.
High-performance forwarding	Bitmap-based lookup and forwarding can be used to reduce device I/O count greatly during forwarding of CGM2 packets and improve entry lookup efficiency.
Fast rerouting upon faults	The FRR mechanism of multicast traffic can be constructed based on the backup route mechanism between the parent and child nodes to implement fast rerouting and forwarding.
Incremental	Tunnels can be automatically established based on device capabilities.

deployment on traditional networks	Compatibility with legacy IP devices and iterative deployment are supported.

2 CGM2 Technology and Deployment Test

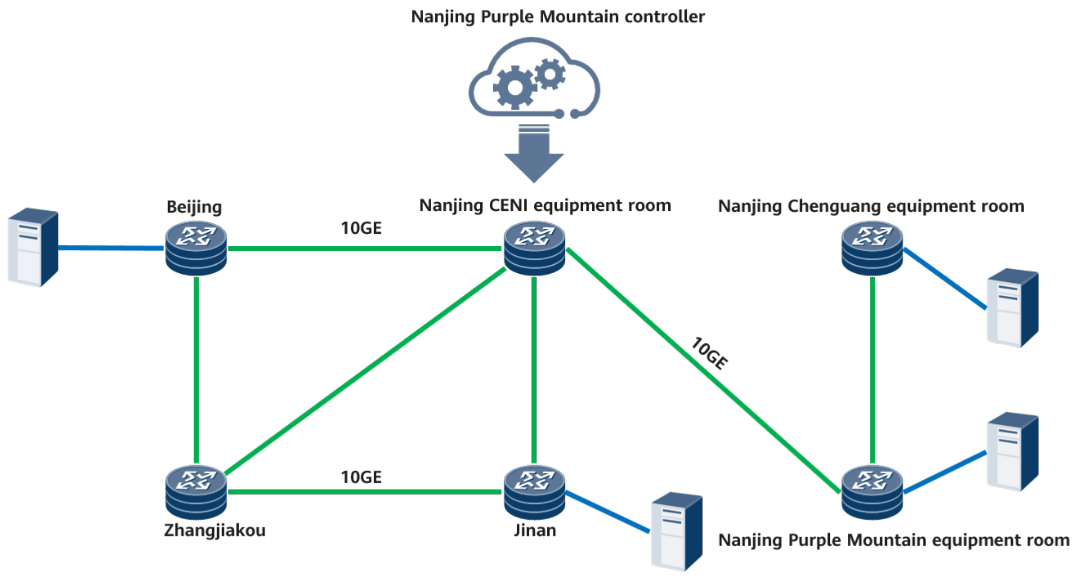
2.1 CENI Backbone Network Deployment and Test

The CGM2 capability deployment and test in phase 1 are based on the China Environment for Network Innovations (CENI) backbone network. The purpose is to deploy prototypes and verify the design principles and performance of CGM2. The test verifies the basic multicast capability of CGM2, explicit path control capability of the ingress node, fast traffic switchover capability upon link faults, and multicast path calculation capability and multicast service performance capability of the network operating system (controller). The test also demonstrates the advanced performance of CGM2's deployment in production network. Table 2-1 describes the test cases.

Table 2-1 Test case list

No.	Test Name	Test Objective
1.1	Cross-province basic multicast capability test	The basic multicast capability test is performed based on the CENI transmission backbone network, which covers a distance of over 1000 km from Beijing to Nanjing. The test verifies CGM2 effectiveness when Beijing is the multicast source and Jinan and Nanjing are the receivers.
1.2	Test of the ingress node's capability of controlling multicast paths	Based on the CENI backbone network, the test verifies the validity of strictly constraining multicast forwarding paths on the CGM2 ingress node in Beijing.
1.3	Test of fast multicast traffic switchover upon link faults	Based on the CENI backbone network, the test verifies the capability of fast switching traffic from the link between Beijing and Nanjing CENI laboratories to a new path when the link fails. The fast switchover prevents data loss on receivers.
1.4	Test of the multicast path computation capability of the network operating system	Based on the CENI backbone network, this test verifies the validity of automatically and manually specifying strictly constrained multicast forwarding paths on the CGM2 ingress node through the network operating system (CNOS) in Purple Mountain Laboratories.
1.5	Test of the multicast service performance detection capability of the network operating system	Based on the CENI backbone network, this test verifies the capability of the network operating system (CNOS) in Purple Mountain Laboratories in displaying various performance statistics of multicast services.

Figure 2-1 Topology of CGM2 on the CENI backbone network



Among the nodes on the CENI backbone network, CGM2 is deployed on six nodes: one node in one equipment room in Beijing, Zhangjiakou, and Jinan, and three nodes (each in one equipment room) in Nanjing. Test flows originate from Beijing equipment room and are distributed to the testers in the Jinan equipment room and Nanjing Chenguang equipment room. The devices along the forwarding paths of the test flows vary according to test cases.

2.2 Cross-Province Basic Multicast Capability Test

In the basic multicast capability test, multicast flows originate from Beijing, and the flows are replicated into two copies. One copy of flows passes through Zhangjiakou and reaches the tester in the Jinan equipment room, whereas the other copy passes through Nanjing CENI equipment room and Nanjing Purple Mountain equipment room and reaches the tester in Nanjing Chenguang equipment room.

Figure 2-2 Schematic diagram for testing the basic multicast capability

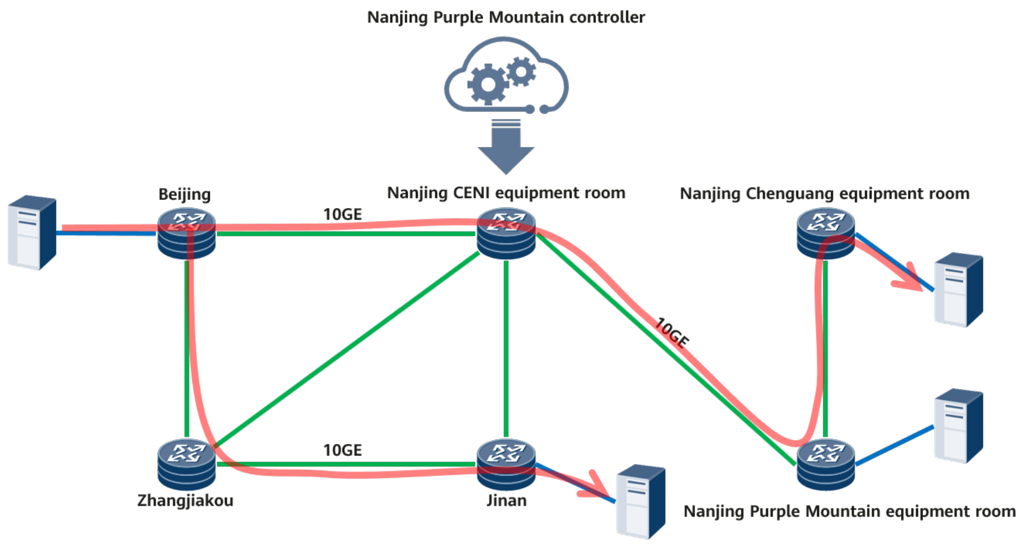


Table 2-2 lists the test flow parameters.

Table 2-2 Test flow parameters

Test flow parameters:	Rate: 8 Gbps; packet length: 1500 bytes; port rate: 10 Gbps

Figure 2-3 shows statistics about the multicast flow throughput (in bps) and statistics about number of data packets during the period from the time when the tester in the Beijing equipment room starts to send flows to the time when the tester stops sending flows. Figure 2-4 and Figure 2-5 show the statistics about the throughput of multicast flows received by the Jinan equipment room and Nanjing Chenguang equipment room (in bps), respectively, and the statistics about number of data packets. According to the test results, the Jinan equipment room and Nanjing Chenguang equipment room receive sufficient multicast data from the Beijing equipment room at the same time. When the Beijing equipment room stops sending flows, the two equipment rooms no longer receive data. This indicates that CGM2 is successfully deployed on the CENI backbone network and that the network has the basic CGM2 multicast capability.

Figure 2-3 Traffic rate and data packet statistics on the Beijing node

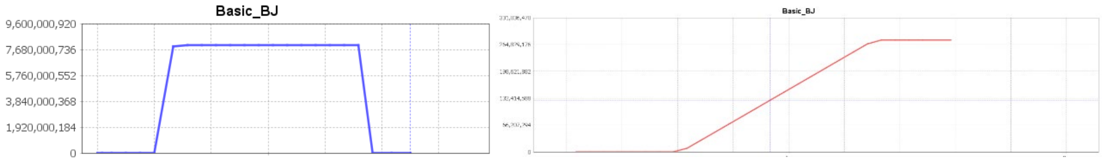


Figure 2-4 Traffic rate and data packet statistics on the Jinan node

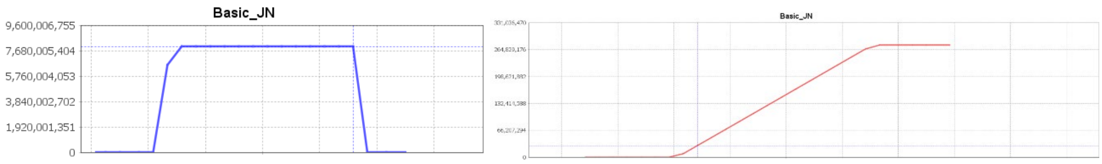
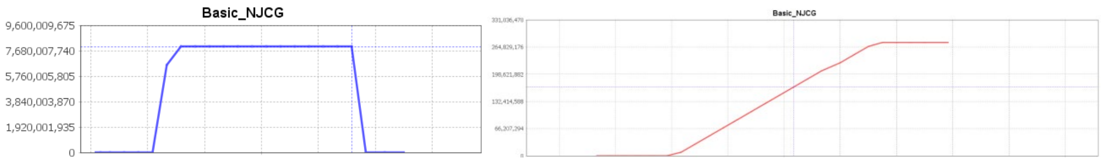


Figure 2-5 Traffic rate and data packet statistics in Nanjing Chenguang equipment room



2.3 Test of the Ingress Node's Capability of Controlling Multicast Forwarding Paths

As shown in Figure 2-6, in the multicast path control test, the ingress node in the Beijing equipment room is configured to divert flows from the original path (Zhangjiakou -> Jinan equipment room) in the basic test case to a new path (Nanjing CENI equipment room -> Jinan equipment room). After the flows are diverted, the multicast replication point is changed from the Beijing equipment room to the Nanjing CENI equipment room. After a period of time, the flows are diverted back to the original path in Figure 2-2. The test result shows that the Jinan node (receiver) is unaware of the change during path switching.

Figure 2-6 Schematic diagram of the path control capability test on the ingress node

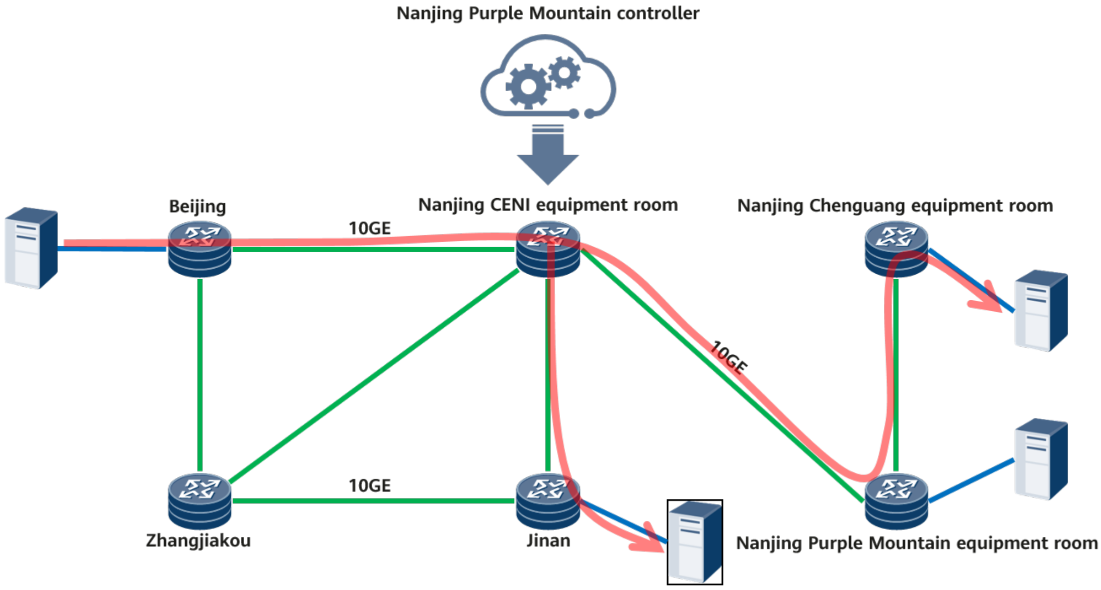


Table 2-3 lists the test flow parameters.

Table 2-3 Test flow parameters

Test flow parameters:	Rate: 2 Gbps; packet length: 1500 bytes; port rate: 10 Gbps

Figure 2-7 shows statistics about the flows sent by the Beijing node. Figure 2-8 shows statistics about the flows received by the Jinan node. Figure 2-9 shows statistics about the flows from the Beijing node to the Zhangjiakou node. Figure 2-10 shows statistics about the flows from the Nanjing CENI node to the Jinan node.

Initially, flows are transmitted from Beijing to Jinan through Zhangjiakou. After path switching is performed in Beijing, the flows are transmitted from Beijing to Jinan through Nanjing CENI equipment room. After a period of time, the Beijing node switches the flows back to the original path. It can be seen from Figure 2-9 and Figure 2-10 that, after the switchover is performed, the flows from Beijing to Zhangjiakou disappear, and the flows from Nanjing CENI equipment room to Jinan immediately appear. In addition, after the switchback is performed, the flows from Beijing to Zhangjiakou recover, and the flows from Nanjing CENI equipment room to Jinan disappear.

Figure 2-7 Flow rate on the Beijing node

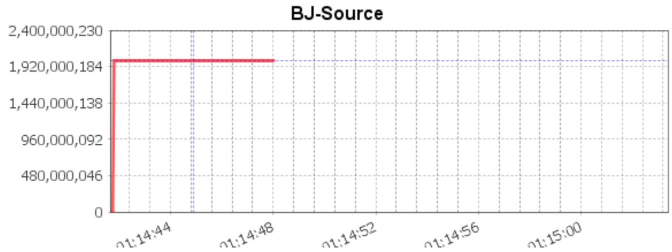


Figure 2-8 Flow receiving rate on the Jinan node

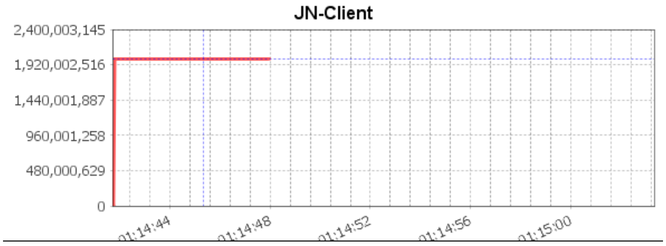


Figure 2-9 Rate of the flows from Beijing to Zhangjiakou

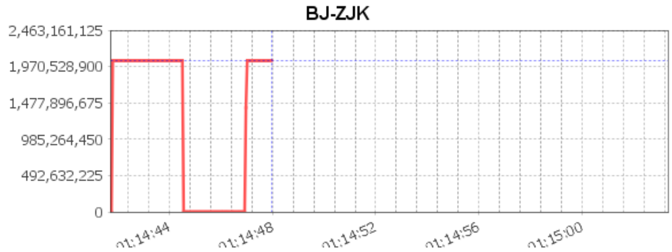
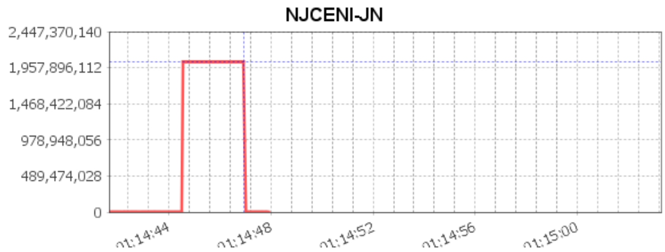


Figure 2-10 Rate of the flows from Nanjing CENI equipment room to Jinan



The test results show that CGM2 helps the ingress node successfully control the traffic forwarding path without affecting the traffic receiving by the multicast receiver.

2.4 Test of Fast Multicast Traffic Switchover upon Link Faults

The fast traffic switchover test is carried out based on the basic multicast traffic test case, and the link between Beijing and Nanjing CENI equipment room is disconnected to simulate a link fault. After detecting the link fault, the CGM2 device in Beijing equipment room quickly switches flows from the current path (Beijing -> Nanjing CENI equipment room) to the backup path. The backup flows are transmitted along the new path (Beijing -> Zhangjiakou -> Nanjing CENI equipment room), with the receiver (tester) in Nanjing Chenguang equipment room almost unaware of the traffic interruption.

Figure 2-11 Schematic diagram of the fast multicast traffic switchover test

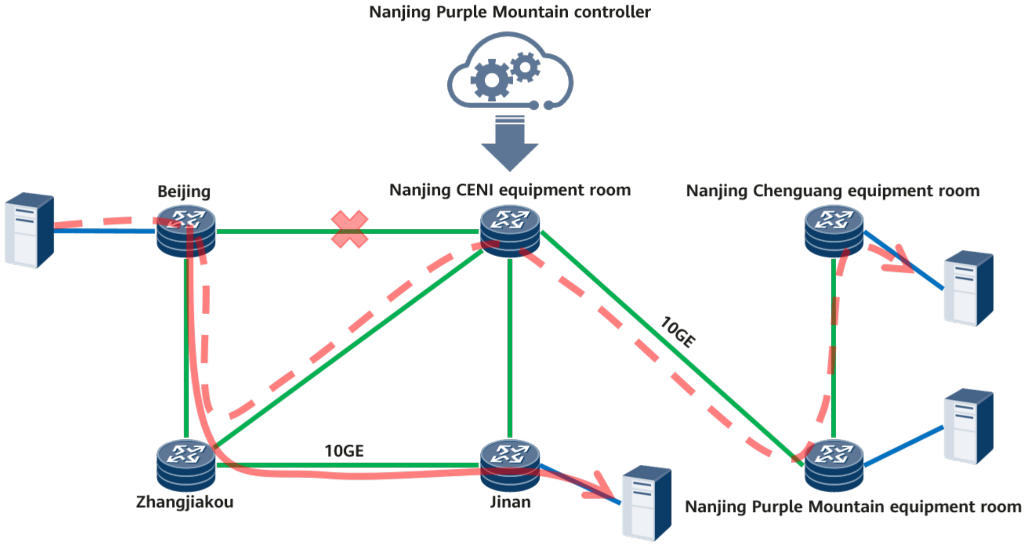


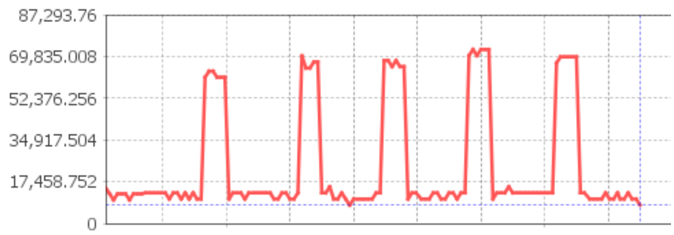
Table 2-4 lists the test flow parameters.

Table 2-4 Test flow parameters

Test flow parameters:	Rate: 4 Gbps; packet length: 1500 bytes; port rate: 10 Gbps

Figure 2-12 shows the traffic interruption time detected by the tester in Nanjing Chenguang equipment room. The vertical axis indicates the interruption durations (in µs), and the horizontal axis indicates the time. As shown in the preceding figure, five link disconnection experiments are performed. After each disconnection, the Beijing node detects the fault and switches flows to the backup path within a period of time. During this period, the tester in Nanjing Chenguang equipment room can detect the traffic interruption, and the traffic interruption durations measured by the tester increase sharply (as shown in the peaks in the figure). As shown in the figure, the traffic interruption durations are between 50 ms and 70 ms. That is, the Beijing node successfully performs switchovers, and the switchover durations are between 50 ms and 70 ms.

Figure 2-12 Result of the traffic interruption durations measured by Nanjing Chenguang equipment room



2.5 Test of the Multicast Path Computation Capability of the Network Operating System

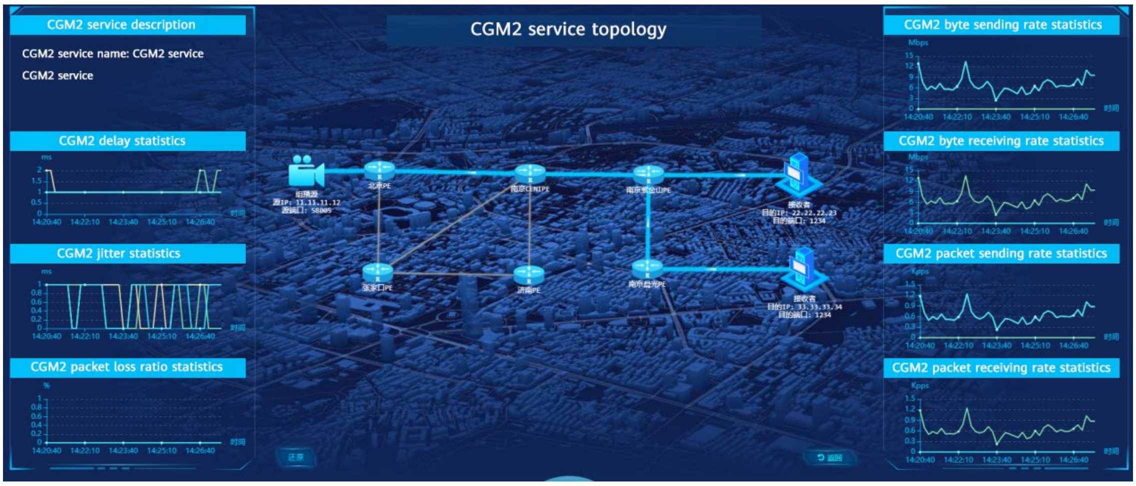
2.5.1 Automatic Multicast Path Calculation

The network operating system (CNOS), i.e. controller, can automatically detect topology changes. In the case of a large service volume, the CNOS periodically monitors the traffic, delay, and bandwidth of links and generates optimal multicast paths based on the global path computation algorithm.

On the CNOS page, we can create a CGM2 service and set the ingress and egress points. If explicit nodes are automatically specified, the control system uses a global path computation algorithm to generate the optimal path based on path computation parameters such as the hop count, link delay, and bandwidth after the service configuration is committed.

After the CGM2 service is created, two paths are generated. Path 1 is multicast source -> Beijing -> Nanjing CENI equipment room -> Nanjing Purple Mountain equipment room. Path 2 is multicast source -> Beijing -> Nanjing CENI equipment room -> Nanjing Purple Mountain equipment room -> Nanjing Chenguang equipment room.

Figure 2-13 Multicast forwarding paths automatically calculated by the network operating system



2.5.2 Manually Specifying Multicast Forwarding Paths

The network operating system (CNOS) allows users to manually set explicit NEs for tunnel paths.

We can create a CGM2 service on the network operating system (CNOS) page, specify the ingress and egress access points, and manually set the explicit nodes for the service paths. Ensure that the specified NE sequence is the same as that in the expected path computation result. After service configurations are committed, the control system computes network-wide tunnel paths based on explicit node parameters and link performance to generate the optimal path that meets explicit node requirements.

After the CGM2 service is created and the explicit nodes (Zhangjiakou -> Jinan) are specified, two paths are generated. Path 1 is multicast source -> Beijing -> Zhangjiakou -> Jinan -> Nanjing Purple Mountain equipment room. Path 2 is multicast source -> Beijing -> Zhangjiakou -> Jinan -> Nanjing Purple Mountain equipment room -> Nanjing Chenguang equipment room.

Figure 2-14 Manually specified multicast forwarding paths

2.6 Test of the Multicast Service Performance Detection Capability of the Network Operating System

After the CGM2 service is created, on the service details page of the network operating system (CNOS), you can view the network topology information, multicast source IP address and port number, receiver IP address and port number, multicast service path, and service performance monitoring statistics obtained by the controller. The statistics cover the following items:

1. Statistics about the delay, jitter, and packet loss ratio on CGM2 paths. The monitoring period is 10 ms. The coordinate axis displays the statistics of the last 7 minutes.
2. Statistics about the byte sending rate, byte receiving rate, packet sending rate, and packet receiving rate of the service interfaces on the CGM2 sender and receiver. The monitoring period is 10 ms. The coordinate axis displays the statistics of the last 7 minutes.

Figure 2-15 Multicast service performance data displayed on the network operating system

3 Analysis on the Capabilities of CGM2

CGM2 has multi-dimensional technical advantages and boasts high performance in basic and advanced multicast capabilities.

- Advanced capabilities

  CGM2 clearly defines the forwarding paths of multicast traffic as it allows an outbound interface to be specified for each forwarding device. In this way, carriers and enterprises can easily steer multicast traffic on the network to simplify control plane protocols, enable load balancing, and implement complex traffic engineering. In addition, CGM2 can easily implement FRR, and forwarding devices only need to maintain a few extra states to cover all faults.

- Scalability

  Although stateless multicast technologies alleviate the pressure of forwarding devices in maintaining the status of entries on the same quantity of multicast flows, scalability still needs to be considered due to the expansion of the network scale and the limitation of device capabilities. That is, the entry status on forwarding devices should be unassociated with the factors featuring rapid growth. The entry status of devices running existing stateless multicast technologies is usually associated with rapidly expanding information, such as the number of edge nodes and the number of network links. Therefore, scalability on a large-scale network is still a bottleneck. However, the number of forwarding entries maintained by each CGM2 device is equal to the number of its interfaces or neighbors and does not increase significantly. Therefore, CGM2 is friendly to large-scale network deployment.

- Network utilization

  The essence of multicast is to efficiently use the network infrastructure, and multicast technologies need to ensure high network bandwidth utilization. Even if a large number of receivers exist, the source is expected to send multicast data only once. Existing stateless multicast technologies face the challenge in meeting the requirement of maximizing bandwidth utilization because the size of multicast information encapsulated in the packet header may be large enough to cause slicing. Therefore, the multicast information carried in the packet header should be as compact as possible. Different from other existing stateless multicast technologies, CGM2 does not need to encapsulate all potential information of the network. Instead, it encapsulates only information about devices related to the multicast service. In addition, the CGM2 encapsulation length can be adjusted based on strict or loose path constraints. In loose mode, multicast forwarding information for some forwarding devices can be omitted. In addition, CGM2 has multiple encapsulation optimization designs which reduce encapsulation overhead. Therefore, in most scenarios, the CGM2 packet header is compact enough to avoid slicing and maximize network utilization.

- Forwarding performance

  Multicast technologies must ensure high forwarding performance. Especially for stateless multicast technologies, forwarding devices tend to read a small number of bits and query a small number of forwarding table entries. In CGM2, a forwarding device parses only its own multicast encapsulation information. It does not read the forwarding information encapsulated for other devices. In addition, the forwarding table is small in size and does not require complex search algorithms. Therefore, CGM2 helps forwarding devices easily obtain high forwarding performance. In addition, CGM2 has no requirement on device hardware. The test prototype used in this experiment supports line-rate forwarding.

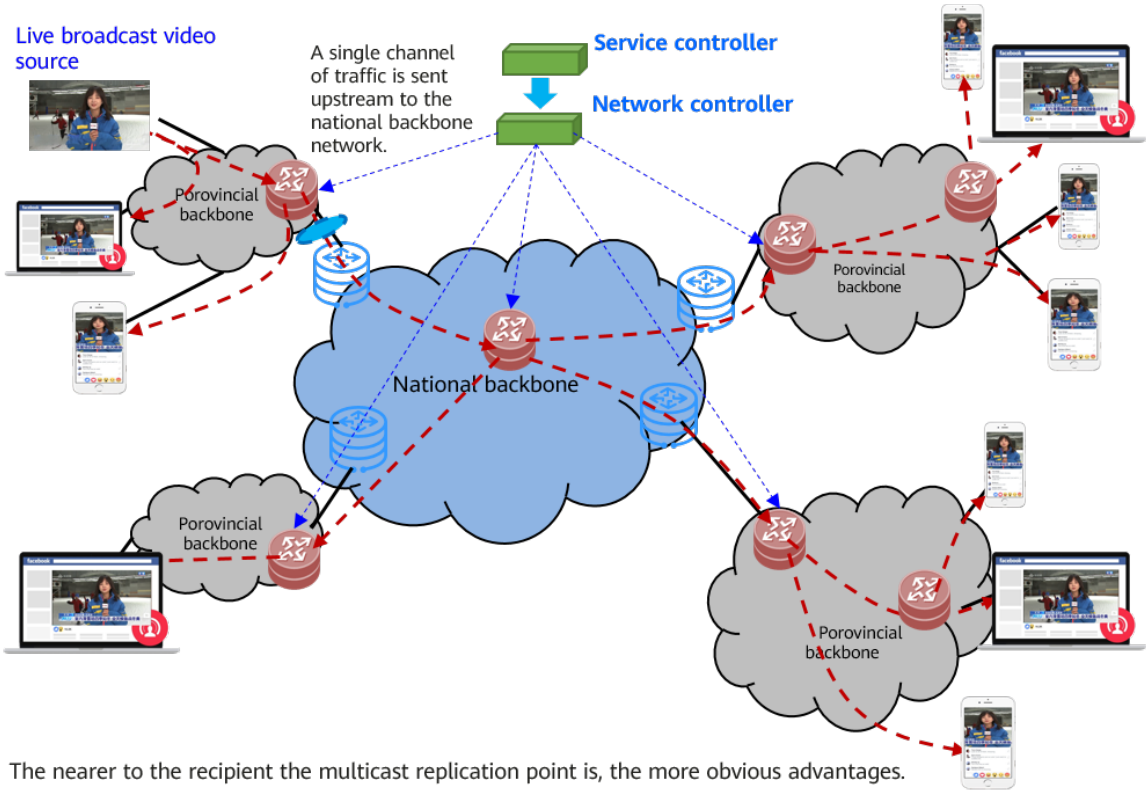
4 Test Conclusion and Test Planning

CENI-Huawei CGM2 networking test (phase 1) — CGM2 capability deployment and test achieves good results. The test environment covers six equipment rooms in Beijing, Zhangjiakou, Jinan, and Nanjing. Purple Mountain Laboratories for Network Communication and Security, Huawei Network Technology Laboratory, Jiangsu Future Networks Innovation Institute, and Beijing University of Posts and Telecommunications jointly carried out the first innovative experiment on CGM2. CGM2 has the advanced capability of controlling multicast paths on the ingress node and the capability of fast switching multicast traffic in the case of a link fault. It has been verified on the CENI backbone network. With the expansion of the communication network scale and the popularity of multicast-based services, multicast technologies face more challenges and opportunities. The multicast technology development is of great significance to the national digital construction and the development of network communication. The success of CGM2 in the CENI experiment is an important milestone for CGM2 deployment (on the CENI network), testing, and verification. CGM2 is expected to help carriers and enterprises to develop more flexible and efficient network communication.

In the future, cloud networks will be widely used, and various new applications will emerge one after another. The CGM2 technology, with the advantages such as efficient encapsulation, stateless forwarding, and multicast path planning, will be widely used in scenarios such as video conferences, remote education, telemedicine, and live streaming.

In the future, the CGM2 research, test, and deployment will be carried out in turn and step by step. The CGM2 technology will be introduced to CCTV's "Hundred Cities and Thousands of Screens" ultra-HD audio and video network for verification, promoting the development of video network technologies, providing more capabilities for future-oriented services, and promoting the continuous evolution of network protocol system technologies.

Figure 4-1 Future experiment plan for CGM2



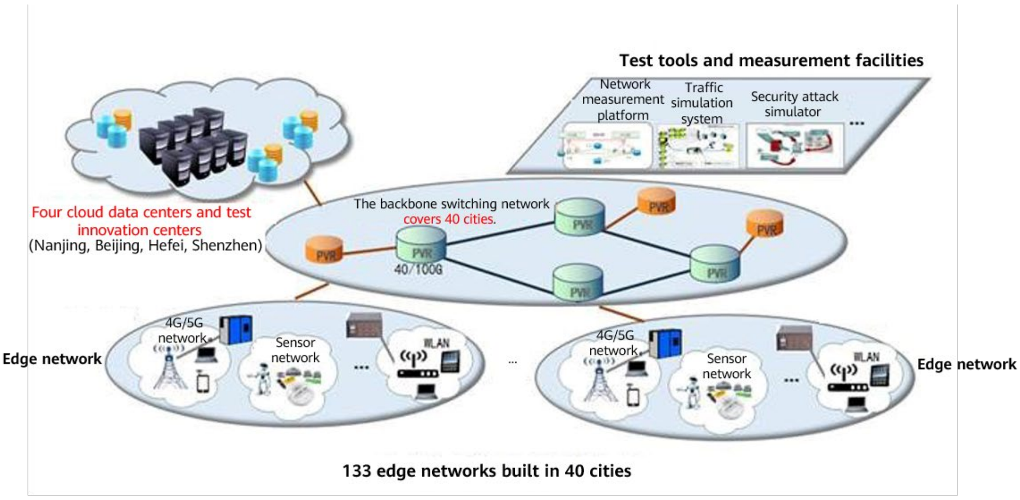
Appendix 1: CENI Network Overview

CENI is China's first major national scientific and technological infrastructure in the information and communications field and the first major national scientific and technological infrastructure project in Jiangsu province. In 2013, this project was listed in the Medium and Long-Term Plan for Key National Technology Infrastructure Construction (2012-2030) of the State Council Doc. No. 8 [2013]. The project proposal was approved in December 2016, and the feasibility study report was approved in May 2018. The government of Jiangsu province is the project management department. The Ministry of Education, Chinese Academy of Sciences, and the government of Shenzhen are co-construction departments of the project. Jiangsu Future Networks Innovation Institute works as the legal entity and leading unit of the project. It cooperates with Tsinghua University, University of Science and Technology of China, and Shenzhen Academy of Information and Communications Technology.

CENI uses the world-leading Service Customized Network (SCN) architecture to provide minute-level on-demand network customization, microsecond-level deterministic assurance, and TB-level intent-driven network security protection. To meet the major technical challenges of the Internet architecture in terms of scalability, security, real-time performance, mobility, and management, the basic theory and core mechanism of the new network architecture are studied. CENI has been applied to more than 10 national important projects, such as the Industrial Internet Benchmark Extranet. It has made a series of major breakthroughs, for example in the world's first large-scale network operating system, the world's first precise control of latency and jitter within 30 microseconds across 2000 km, and the industry's first device-level operating system that adapts to multiple mainstream heterogeneous switching chips. Among them, Service-Oriented Future Network Experiment Environment and Technology Innovation was successfully selected as the leading scientific and technological achievements of the 7th World Internet Conference 2020 in Wuzhen.

In October 2021, CENI publicly solicited innovation experiment requirements nationwide for the first time, indicating that the door of facilities was officially opened to the whole society. It drew great public attention and interest. China's top research institutes, three major telecom carriers, leading enterprises such as Huawei, and famous universities such as Xi'an Jiaotong University, have reported more than 40 strategic, basic, and forward-looking experiment requirements, covering major national strategies, cutting-edge technology innovation, and emerging industries and applications. Participants in this batch of innovation experiments are of high level and representative, fully demonstrating the appeal of CENI as a major national scientific and technological infrastructure. Compared with other national scientific apparatus, CENI has more prominent cross-domain and cross-disciplinary support capabilities and industry service capabilities under different scale conditions.

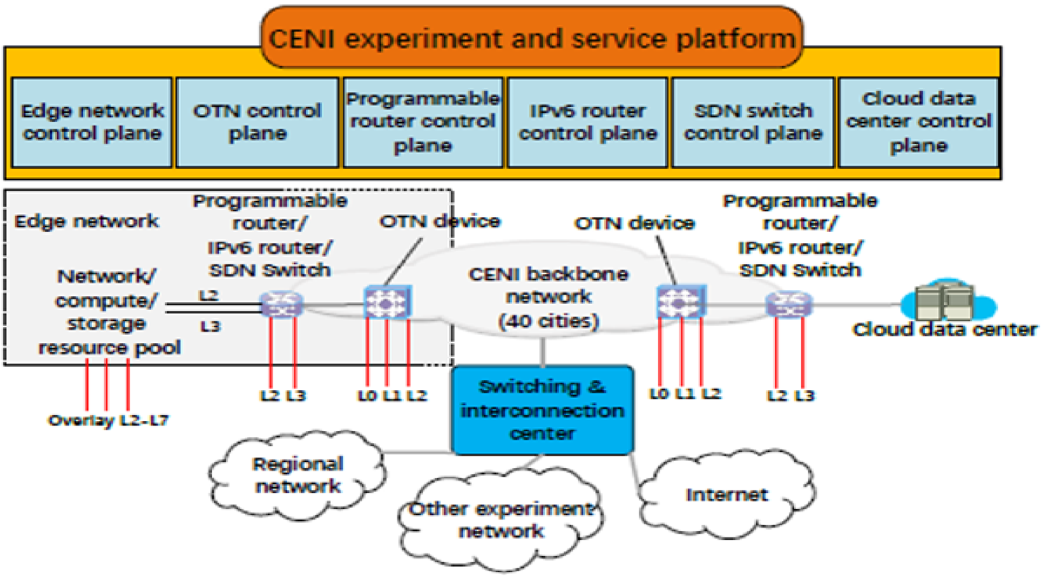
Figure A-1 CENI networking



CENI will continue to focus on China's strategic requirements for technology power and cyberpower, with the mission of leading the global future network development direction and resolving major scientific and technological issues in the industry, aiming to make breakthroughs in key core technologies. In addition, CENI will continue to focus on forward-looking and basic research, carry out major demonstration applications, promote the implementation of achievements in national economic construction, comprehensively promote the construction of the "CENI+" innovative ecosystem, and explore the technical roadmap and development path suitable for China's future network development. CENI will help China take the initiative in the international competition in cyberspace in the fifth territory of humankind besides the sea, land, air, and sky, and make greater contributions to helping China win the second half of the Internet.

The design of CENI's overall science and technology solution complies with basic principles, such as requirement-driven development, unified top-level design, both stability and advancement, and full resource sharing. CENI provides an advanced, open, flexible, high-speed, and reliable experiment environment for multi-scenario network innovation technologies and applications at L0 to L7.

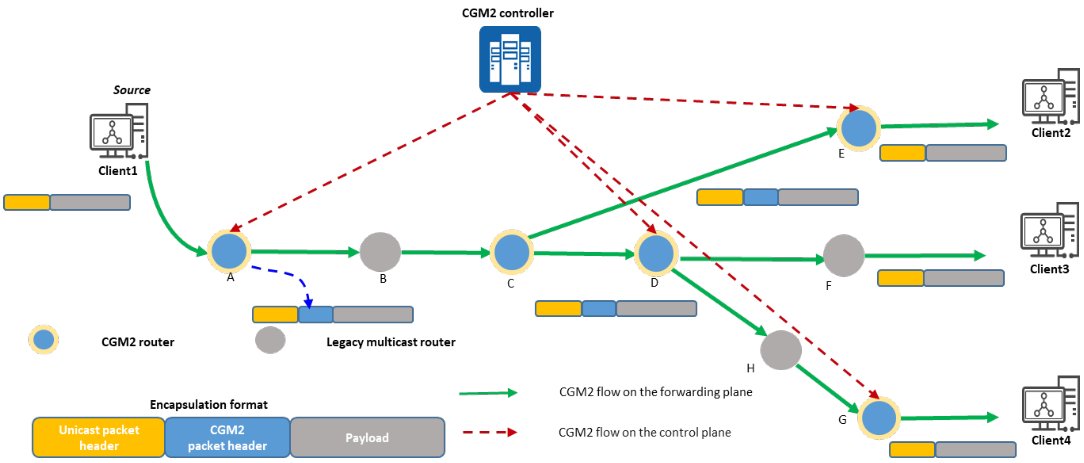
Figure A-2 CENI system architecture



Appendix 2: Overview of CGM2

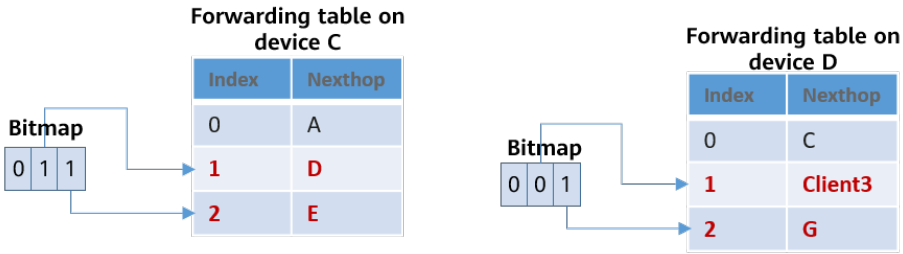
The objective of CGM2 is to provide multicast technologies that are operable on large-scale networks for network transmission devices. This not only meets the requirements of wide-ranging multicast services, provides better service experience, but also promotes the upgrade and development of related industries.

Figure A-3 Application architecture of CGM2



CGM2 uses localized multicast route identifiers in the bitmap form to control multicast forwarding of network devices. Each bit in the bitmap corresponds to a multicast neighbor (or an entry in the multicast neighbor table), as shown in the following figure. The Nexthop field in the entry indicates the multicast neighbor. A multicast device replicates and forwards packets to all multicast neighbors whose corresponding bits in the bitmap are set to 1.

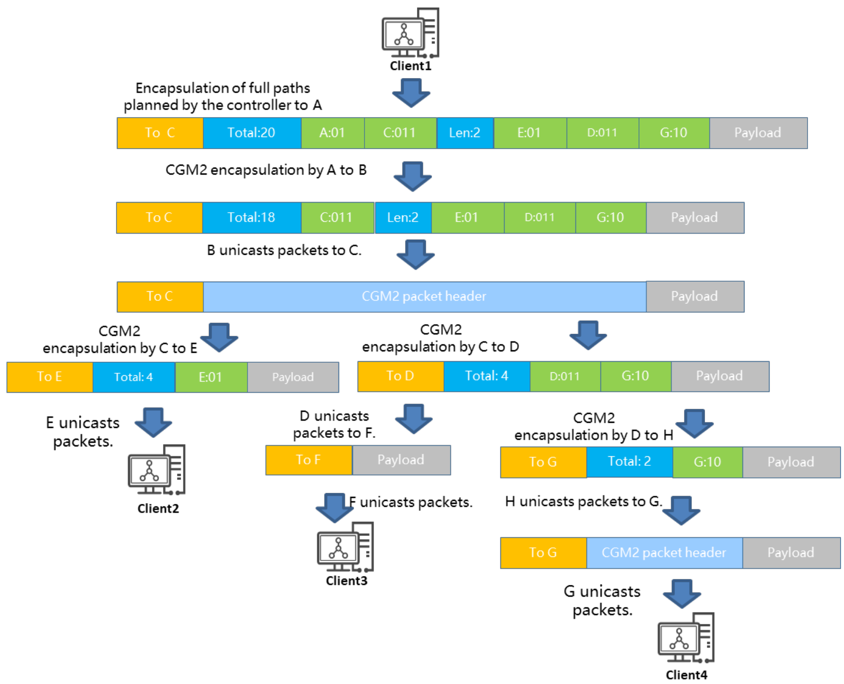
Figure A-4 Multicast neighbor table



In the CGM2 technology, a controller calculates multicast route identifiers of all nodes on a multicast path, organizes the multicast route identifiers into a complete bitmap multicast encapsulation in a tree structure, and delivers the encapsulation to the first node (a multicast source or a first-hop multicast device) on the multicast path.

Packets carrying multicast route identifiers in bitmap form are transmitted between devices, as shown in the following figure. Each multicast device searches the multicast neighbor table based on the multicast route identifier corresponding to the current node in the packet to perform multicast forwarding. Therefore, the CGM2 technology does not require devices to maintain per multicast flow forwarding entries. In addition, the CGM2 technology has the capability of specifying multicast paths.

Figure A-5 Encapsulation of CGM2 packets



The CGM2 technology supports mixed deployment, sparing the need to replace or upgrade all devices on the entire network. The packets received by legacy routers on the multicast transmission path are still common unicast packets and are forwarded based on their destination IP addresses. The CGM2 technology supports underlay or overlay deployment, featuring flexible deployment and easy capacity expansion. The CGM2 technology can easily construct point-to-multipoint transmission channels, provide SLA-guaranteed service provisioning, and implement delay and jitter control and fast failover. Centralized and visualized O&M is implemented on the control plane. On the forwarding plane, per multicast flow configuration does not need to be performed, and multicast services on devices along the entire forwarding path are also maintenance-free. CGM2 provides a set of carrier grade multicast technologies that ensure efficient O&M and high reliability.