Research on 5G optical transport schemes

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Abstract: With the rapid development of 5G technology, its network architecture has changed a lot compared with 4G, which brings many challenges to optical transport network. In this paper, we first discuss the network architecture difference between 4G and 5G. Then, we investigate the optical transport schemes of 5G network, including fronthaul schemes, middlehaul schemes and backhaul schemes, respectively.

1. Introduction
With the rapid development of communication technologies, new application situations in the field of information communication have been proposed in past years, such as 4K/8K ultra-high definition video, VR/AR, automatic driving, industrial interconnection automation, intelligent logistics and intelligent medical treatment. The current 4G network has the problems of insufficient bandwidth, large latency time, and low precision, which cannot meet the needs of new applications in the future. As the next-generation communication technology, 5G has more bandwidth and a low network latency. It will be used to implement enhanced mobile broadband services (eMBB) with higher bandwidth and lower delay, ultra-low latency communication service (uRLLC) and large-scale machine communication service (mMTC) supporting massive user connections. In order to meet these business requirements, it is necessary to study a new type of network architecture. The 5G network architecture has a series of adjustments based on the 4G network architecture. For example, the centralized unit (CU) and distributed unit (DU) have been separated from original 4G base band unit (BBU) and middlehaul between the CU and the DU has been created. These changes in the 5G network architecture have put forward six new demands on the transport network, including large broadband demand, low latency requirements, high-precision time synchronization requirements, flexible networking requirements, network slicing requirements, and flexible routing requirements. The existing transport network is difficult to meet the requirements of future 5G development and fully applied to various services. Therefore, it is necessary to construct corresponding fronthaul and middlehaul transport schemes to meet the needs of the 5G transport network. In this paper, we will discuss and analyze different 5G fronthaul and middlehaul transport schemes.[1-2]

2. The network architecture differences between 4G and 5G
In 5G network architecture, the 4G BBU, radio remote unit (RRU), and antenna are reconstructed into CU, DU and active antenna unit (AAU). The CU is separated from the non-real-time part of the original BBU, and is responsible for handling non-real-time protocols and services. Part of the physical layer processing function of the original BBU, original RRU and passive antenna are combined together and reconstructed into AAU. The remaining functions of the BBU are redefined as DU and are responsible for handling physical layer protocols and real-time services.
Evolved packet core (EPC), which is the core network of 4G, is divided into two parts, New Core (5G core network) and mobile edge computing (MEC). The MEC is deployed to the edge data center, which is much closer to users.[2] Meanwhile, a part of the computing and content storage functions undertaken by the core DC are accordingly sinking to the edge of the network.

3. Discussions on the 5G fronthaul schemes

3.1. Fiber direct connection scheme
In fiber direct connection scheme, each port of DU and AAU uses fiber point-to-point direct connection mode. Each base station only needs 6-core fiber. If single-fiber bidirectional working mode is adopted, each base station needs three-core fiber for DU. Figure 1 shows the principle of fiber direct connection scheme. The fiber direct connection method is simple to implement, but the demand for fiber optic cable resources is large. In the 5G era, with the sharp increase of fronthaul bandwidth, the number of base stations and the number of carries, the consumption of optical fibers in the fiber direct connection scheme can not be neglected. Therefore, if single-fiber unidirectional module is adopted, the demand for optical cables will be greatly increased. Therefore, this solution is only applicable to areas where fiber optic cable is abundant. For areas where fiber resources and pipeline resources are scarce, this scheme cannot meet business needs.[3]
3.2. Passive wavelength division multiplexing (WDM) scheme
The passive WDM scheme exploits WDM technology to install the colorful light module on the wireless device. The functions of WDM are realized by the combined or split wave board cards or devices. Multiple connections between AAU and DU can be provided by using one optical fiber. The schematic diagram is shown in Figure 2. According to properties of the adopted wavelength, the passive WDM scheme can be further divided into coarse wavelength division multiplexer (CWDM) and dense wavelength division multiplexer (DWDM) schemes, respectively. Passive WDM technology can effectively save fiber resources. Each base station only needs 2-core fiber. However, this scheme also has some limitations. First, CWDM technical standard defines 16 channels. However, considering the dispersion problem, the passive CWDM scheme for 5G fronthaul can only use the first few channels. The number of wavelengths is limited, and the scalability is poor. Second, the passive WDM scheme requires different wavelengths for each AAU. Wavelength planning and management should be done in advance for each base station, and the expense of the tunable color optical module is high. Third, the existing operation administration and maintenance (OAM) mechanism and protection mechanism cannot be applied to the color light module, which has a certain impact on the subsequent operation and maintenance management. Fourth, it is difficult to confirm the place of malfunction. After the malfunction of the passive WDM scheme, it is difficult to specifically define the responsible part of the problem.

Compared with the passive CWDM scheme, the passive DWDM scheme obviously can provide more wavelengths. However, more wavelengths also mean higher wavelength planning and control complexity. It usually requires tunable lasers, resulting in higher cost. The DWDM scheme can be divided into two types, including a passive DWDM scheme based on tunable wavelengths and a new passive DWDM scheme based on remote concentrated light sources. The advantages are as follows. First, the AAU/RRU sidelight module is passive, so all optical modules are identical without difference of wavelength. It is called colorless or passive and greatly reduces the cost and improves the reliability and the convenience of maintenance. Second, the light source is centrally deployed. A concentrated light source is set at central office (CO) node, and a direct current optical signal is transmitted to each passive module node. The passive optical module receives the continuous light wave from the concentrated light source and modulates it into a signal light, and turns it back to the CO node to achieve uplink.

Therefore, the next-generation passive solution based on concentrated light source not only inherits the advantages of traditional passive solutions, such as fiber-saving, low cost, and convenient insertion into wireless devices, but also complements the shortcomings in reliability, operation and maintenance management. It is a competitive program of 5G fronthaul transport scheme.[4]

![Figure 3. The schematic of passive WDM scheme](image)

3.3. Active WDM/OTN scheme
The OTN scheme establishes WDM devices at the AAU site and the DU station, and the fiber resources are shared through the WDM technology. In this way, point-to-point or ring network connection can be achieved, which is shown in figure 3. Compared with passive WDM scheme, the
OTN device performs functions such as OTN transport, port aggregation, and color light zoom. This scheme can provide the following functions. First, through the natural convergence function of active devices, it can meet the needs of a large number of AAU aggregation network. Second, network functions such as performance monitoring, alarm reporting, and device management are guaranteed through efficient and complete OAM management.[5] The maintenance interface is clear, and the manageability and serviceability of the fronthaul network are improved. Third, it provides protection and automatic switching mechanism through optical layer protection and electrical layer protection. Real-time backup, fault-tolerant and disaster-tolerant of the fronthaul link can be realized through the main-prepared fiber routing of different pipelines. Fourth, it has flexible equipment form, adapting to the diversification of AAU equipment form and installation methods after concentrated deployment, including indoor and outdoor. For the outdoor type, it can realize various installation methods such as hanging towers, poles and wall hangings, and can meet the requirements of outdoor protection and working environment. Fifth, it supports fixed-line mobile convergence transport and has comprehensive service access capabilities, including fixed broadband and leased line services. Current OTN solutions are relatively expensive, and in the future, cost can be reduced by using non-coherent overclocking techniques or low cost pluggable optical modules. At the same time, OTN technology needs to be simplified to meet the low cost and low latency requirements of 5G fronthaul.

3.4. WDM-PON scheme
The WDM-PON scheme connects AAU to optical network unit (ONU) and uses wavelength division multiplexing. Each ONU communicates with the optical line terminal (OLT) passive optical network (PON) port in a point-to-point manner through a dedicated wavelength. The OLT is connected to the DU through a two-stage splitting light mode. Each base station to DU requires a 1-core fiber to save access to the fiber used by the trunk. The network architecture is shown in Figure 4. The WDM-PON scheme can effectively save fiber resources, especially for areas where the urban 5G base station is densely distributed, and the light is concentrated by the splitting point, which greatly reduces the demand for the trunk fiber.

Figure 4. The schematic diagram of OTN scheme

Figure 5. The schematic diagram of WDM-PON scheme
Table 1. The detail comparison of four fronthaul schemes for 5G network

| Schemes          | Fiber direct connection | Passive WDM | OTN | WDM-PON |
|------------------|-------------------------|-------------|-----|---------|
| Protection       | Low, no protection      | Low         | high|         |
| OAM              | The maintenance interface is ambiguous, and the operation and maintenance of the transmission side is difficult. | The operation and maintenance are unchanged, the transmission fault cannot be detected by the network management; the corresponding situation of the near-end module channel needs the account record. | Easy to maintain |         |
| Network topology | Point to point          | Point to point | Point to point, chain type, ring | Tree shape |
| Time delay       | -                       | Small       | Big | small   |
| Equipment maturity | high                   | High        | high | Lower   |
| Overall costs    | High core demand and low cost | Low core demand and moderate cost | Low core demand and high cost | Significantly save fiber resources, but the cost of the device is too high |

The detailed comparison of the above four fronthaul schemes are shown in Table 1. By comparison, it can be seen that the passive WDM scheme may be the most promising scheme for future application.

4. Discussions on the middlehaul/backhaul scheme of 5G

The 5G middlehaul and backhaul have basically the same requirements for the transport network in terms of bandwidth, networking flexibility, network slicing, etc. So a unified transport scheme can be adopted.

The metropolitan area OTN network architecture includes backbone layer, aggregation layer, and access layer. The backbone layer/aggregation layer corresponds to the 5G backhaul network, and the access layer corresponds to fronthaul and middle haul.

The OTN-based 5G middlehaul/backhaul transport solution can utilize the powerful and efficient frame processing capability of the packet-enhanced OTN, and complete fast framing, compression decompression and mapping functions through dedicated hardware such as Field Programmable Gate Array (FPGA), dedicated chip, and Digital Signal Processing (DSP). It can effectively implement the functions of the DU transmission connection that are extremely sensitive to the delay requirements of the air interface MAC/PHY. At the same time, the packet-enhanced OTN constructs a super-wideband and connection with ultra-low latency between CU and DU, and effectively implement real-time, efficient and reliable PDCP processing, and supports fast signaling access. And the integrated WDM capability of packet-enhanced OTN enables long distance transmission to the suburbs and increases the bandwidth capacity of the transmission link as needed.

The OTN-based 5G middlehaul/backhaul transport scheme can be subdivided into the following two networking modes.

4.1. Packet enhanced OTN+IP RAN scheme

Figure 6 shows the principle of packet enhanced OTN+IP RAN scheme. The middlehaul part uses a
packet enhanced OTN device that enhances the route forwarding function. The backhaul part continues to use the existing IPRAN transport architecture. The packet enhanced OTN and the IPRAN exchange routing information through the BGP protocol. IPRAN needs to introduce high-speed interface technologies such as 25GE (Gigabit Ethernet), 50GE, 100GE, etc., and considers adapting new interfaces such as FlexE (Flexible Ethernet) to achieve physical isolation and provide better bearer quality assurance. This can meet the requirement of 5G transport for large capacity and network slicing.

Figure 6. The schematic diagram of Packet enhanced OTN+IP RAN scheme

4.2. End-to-end packet enhanced OTN scheme

Figure 7 shows the principle of end-to-end packet enhanced OTN scheme. The solution is implemented by a packet enhanced OTN device that enhances the routing and forwarding function. Compared with the packet-enhanced OTN+IPRAN scheme, this scheme can avoid the problem of interworking and inter-professional coordination between packet-enhanced OTN and IPRAN, so as to better utilize the powerful networking capabilities and end-to-end maintenance and management ability of packet-enhanced OTN.[6]

Figure 7. The schematic diagram of end-to-end packet enhanced OTN scheme

5. Summary

With the development of network communication technology, 4G is unable to meet the needs of some emerging businesses. The 5G that emerged at the historic moment is not only the upgrading of mobile communication technology, but also the foundation of the development of the Internet of Things in the driving platform of the digital world in the future. EMBB, mMTC, and uRLLC will become the three major services in 5G applications. The requirements for large bandwidth, low latency, high-precision time synchronization, flexible networking, network slicing, and flexible routing are proposed for 5G. The industry proposes optical transport schemes for fronthaul, middlehaul and backhaul for 5G transport network. For different regions and application scenarios, it is necessary to consider the cost performance ratio of different transport solutions. Although the prototype of the 5G network architecture has been formed, the current technical theory is not mature enough. The large-scale
application of 5G needs to be realized through continuous experiment, research and exploration. 5G is the key to the digital transformation of economic social in the next few years. Grasping the development opportunities of 5G mobile communication and accelerating scientific and technological innovation become a strategic choice for future economic development and international competition. The construction of 5G network needs a large amount of manpower and material investment in the next few years. The planning of the 5G transport network needs to be arranged in advance as a construction of infrastructure.

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