Smart OLT equipment of optical access network

TANG Zhifei*, **GAO Junshi, YANG Tianpu, LIU Dongmei, and DAI Guangchong**
China Mobile Group Design Institute Co., Ltd., Beijing 100080, China

(Received 24August 2022; Revised 7 November 2022)

A distributed architecture of optical line terminal (OLT) equipment is proposed for response to national bandwidth acceleration requirements and for future smooth evolution to 50G passive optical network (PON). This architecture moves the forwarding function of the control board to each service board to improve the switching capacity and performance of the system. The traditional control boards of centralized architecture OLT equipment have exchange and traffic processing function, and every service board is only controlled by the control board. In the distributed architecture of OLT equipment, control boards still maintain exchange function, whereas service boards have traffic processing functions. This method separates the exchange and traffic processing functions, which improves reliability. This paper also presents optical access network equipment combined with telemetry technology that provides reliable guarantee for intelligent analysis and data mining. Compared with the traditional push mode of network management, the data collected by network management combined with telemetry technology and artificial intelligence (AI) analysis can be used for network planning, assurance of the bandwidth and accurate operation.
Document code: A **Article ID:** 1673-1905(2023)03-0159-5
DOI https://doi.org/10.1007/s11801-023-2146-6

In 2020, the National Development and Reform Commission presents explicitly that optical fiber broadband networks are included in the new infrastructure, to support the needs of high-quality development, digital transformation and intelligent upgrading. In the F5G era, the gigabit-capable passive optical network (GPON) was upgraded to the 10G passive optical network (PON) by only replacing the board of optical line terminal (OLT) equipment. With the software defined network (SDN) being deployed on the inter-provincial and provincial optic transport network, the intelligent function of the optical access network is also gradually becoming necessary. The customer experience of optical access is a problem that needs to be improved urgently. If there is a problem in the network, passive problem handling is difficult to meet the good experience of the customer. At the same time, in view of the differentiated business needs of the customer, the current unified quality assessment of the network cannot directly feedback the customer's experience. The location of the network deployment makes it difficult to locate the fault, and the troubleshooting time is long, which brings great difficulties for the operation and maintenance personnel. Traditional 10G PON equipment is difficult to meet the needs of intuitive feedback customer experience and accurate fault location. Therefore, it is urgent to upgrade the processing capacity of existing equipment and network management collection capacity.

Traditional OLT device optical access networks adopt centralized architecture, which leads to the capacity and performance bottleneck of the central forwarding engine. Therefore, the current centralized architecture of OLT cannot cope with the next generation of large-capacity next generation PON applications.

This paper proposes a distributed OLT architecture, which moves the forwarding function of the control board to each service board to solve the current bottleneck. Telemetry technology is used in optical access network equipment which can obtain high accuracy of data collection.

An optical access network consists of an OLT on the terminal side, an optical network unit (ONU) on the user side, and an optical distribution network (ODN). In the downlink direction (OLT to ONU), optical signals from OLT are sent by each ONU using broadcast technology. In the upstream direction (ONU to OLT), the optical signal from ONU is sent exactly by the OLT. In order to avoid data conflict and improve network utilization efficiency, the upstream direction adopts time division multiple access (TDMA) technology that arbitrates data transmission of each ONU. The ODN consists of an optical fiber, many passive optical splitters and related passive optical devices, which provides an optical transmission channel between the OLT and ONU.

The traditional architecture of OLT device has two pieces of control board that simultaneously complete the function of data forwarding and traffic processing, and the main control board and spare control board adopt load sharing. This centralized architecture relies on the central forwarding engine to perform table-lookup forwarding for each input packet. Based on the latest capacity estimation of the current industry chain, when the

* E-mail: tangzhifei@cmdi.chinamobile.com

switching capacity expands to a certain extent, the single user slot rate is more than 100G/200G, or the lookup table entries reach a certain extent, such as the number of practical media access control (MAC) addresses in the Layer 2 scenario exceeds 128k, the number of practical Internet protocol (IP) addresses in the Layer 3 scenario exceeds 32k, and the power consumption of a single chip will exceed the OLT cooling capacity, causing the system to overheat. Or the size of the table item exceeds the limit of a single chip, resulting in the inability to learn the user address, the inability to open the ONU to the PON channel, and the inability of users to access the Internet. Therefore, the central forwarding engine becomes a bottleneck in capacity and performance.

In the distributed architecture OLT, the chip of main control board is only responsible for the exchange function. Under the current mainstream chip process conditions, it is easy to obtain the single slot 1T switching capacity. The main control board still maintains the equipment network management function, but the data forwarding function is transferred from the main control board to each service board. Each service board has its own forwarding engine, which can independently search and forward messages. Since the processing bandwidth of each service board is only 1/16 of that of the main control board/uplink board (calculated according to the 16 slots of the subrack), the forwarding chip has a large margin to increase the forwarding table entries. For example, the number of practical MAC addresses in the Layer 2 scenario can reach 256k or even more than 1M, and the number of practical IP addresses in the Layer 3 scenario exceeds 128k.

Tab.1 Comparison of MAC address and IP address items in traditional and distributed OLTs

Item	Traditional OLT	Distributed architecture OLT
MAC address	Highest to 128k	256k or even more than 1M
IP address	Highest to 32k	Exceeding 128k

The function of data forwarding is transferred from the control board to each service board. Every service board has its own forwarding engine, which independently completes packet lookup and forwarding.

The distributed forwarding architecture greatly improves the switching capacity and performance of the system. It can also build a high-capacity strictly non-blocking system. Realize the switching capacity of 1T in a single slot. The current mainstream PON cards are all 16-port access, and the single slot 1T access capability can provide 16-port 50G PON line speed forwarding capability, laying a platform foundation for the future 50G PON evolution. We have compared the switching capability and chip manufacturing difficulty of traditional and distributed switching architectures through experiments. The specific details are shown in Fig.1. The experiment shows that the chip manufacturing is very difficult and cannot be achieved if the traditional architecture OLT is used to achieve 50G PON forwarding in the future. However, the distributed architecture OLT switching can meet the 50G forwarding rate per port of the line with the current chip manufacturing level.

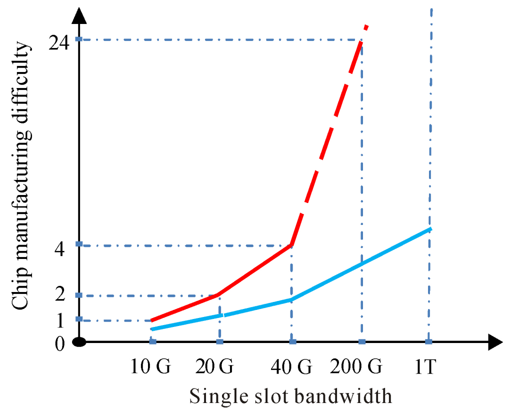

Fig.1 Comparison of OLT switching capability and chip manufacturing difficulty between traditional and distributed switching architectures

System reliability of parallel system can be roughly calculated by the following formula as

$$P=1-(1-P_1)\times(1-P_2)...\times(1-P_n), \quad (1)$$

where P refers to the reliability of equipment, and P_i (i=1, 2, 3..., n) refers to the reliability of each component (the reliability of each service board). The reliability of centralized architecture equipment comes from two parallel forwarding engines (in case of dual forwarding engines), so the system reliability is $P=1-(1-P_1)^2$. The reliability of distributed architecture equipment comes from multiple distributed forwarding engines, so the system reliability is $P=1-(1-P_1)^n$. Hypothesis P_1=0.8 then centralized reliability. P=0.96 distributed reliability (the equipment has four service boards) P=0.998 4. So the reliability of distributed architecture is higher than that of centralized architecture, and the higher the reliability with the increase of the number of service boards.

The traditional data collection polls data in the data resource pool, this collection due to the limited storage speed and long cycle of acquisition, accuracy of data collection is not suitable for the current development trend of data applications, such as data analysis, data mining, deep learning and anomaly detection, etc. Common structured network monitoring methods include simple network management protocol (SNMP) Get and SNMP Trap. The precision of SNMP Get mode pulls data at the minute level, which determines a large number of network nodes that cannot be monitored. In addition, at the minute level of the sampling period, the accuracy of the data cannot be guaranteed. The front and back beats of sampling will deviate by more than 10 s. To speed up the sampling frequency, the central processing unit (CPU) of the node will increase to more than 80%, causing the risk of system overload. The SNMP Trap adopts push mode, and its accuracy is greatly reduced to the second level. However, the biggest problem is that the accuracy of data is low and the collected data may easily be lost.

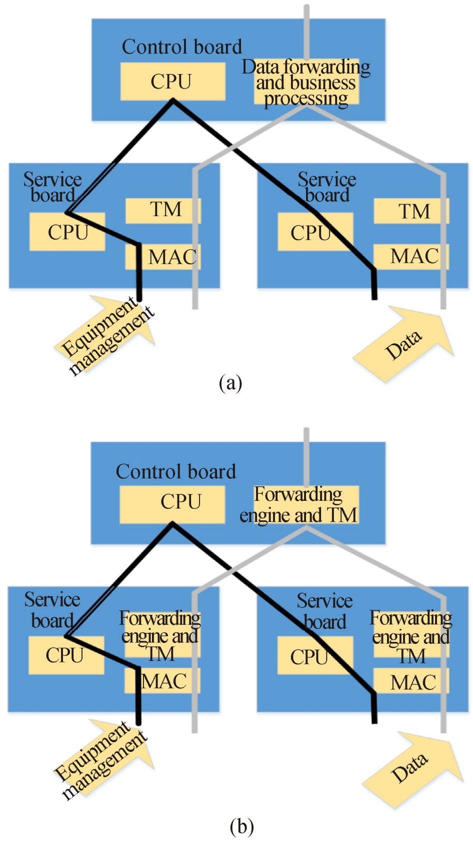

Fig.2 (a) Centralized architecture and (b) distributed architecture

We have come to the conclusion that data analysis should have strong real-time performance and high accuracy of push technology. Then, the introduction of telemetry acquisition technology can realize data acquisition based on data application. Telemetry is a remote high-speed data acquisition technology from physical devices or virtual devices. In push mode, the device proactively sends device data to the collector, providing real-time and high-speed data collection.

Telemetry features several aspects as follows.

(1) Refinement: It has high precision to collect interface traffic information that judges packet loss and analyses occupancy of CPU and memory, and it also gathers link status and user traffic jitter.

(2) High efficiency: Telemetry technology adopts active push mode so that OLT devices periodically automatically push data to network management, it avoids repeated queries and improves higher execution efficiency of monitoring performance.

(3) Good real-time performance and accuracy: It supports the accuracy of millisecond level.

(4) Meet the requirements of intelligent operation and maintenance: It has little impact on the function and performance of the device itself, and provides the most important basis for big data analysis to quickly locate network problems, thereby optimizing and adjusting network quality.

(5) Standardization: It supports structured and unified data formats among different manufacturers. Different manufacturers can use the same set of acquisition and analysis tools.

Telemetry network monitoring enables the network intelligent operation and maintenance system to manage more than 10 times the number of equipments. The accuracy of monitoring data has improved from minute level to millisecond level with higher accuracy. The monitoring process has little impact on the function and performance of the equipment itself. Monitor network status timely tuned network by providing data support in real time. After the tuning instruction takes effect, the new sampling data will be fed back to the collector to provide data support for analyzing whether the adjusted effect meets expectations.

Tab.2 Comparison of different network monitoring methods

Comparison item	Telemetry	SNMP Get	SNMP Trap
Operating mode	Push mode	Pull mode	Push mode
Carrying protocol	TCP/UDP	UDP	UDP
Refinement	High	Low	Middle
Efficiency	High	Low	Middle
Real time and accuracy	Sub-second level	Minute level	Second level, easy to lose data and affect the judgment of results
Meet the requirements of intelligent operation and maintenance	Satisfied	Not satisfied	Not satisfied
Standardization	Standardized and easy to understand	Non-standardized and difficult to understand	Non-standardized and difficult to understand

The network management sends telemetry configuration data to the OLT device by using the YANG model. The OLT device periodically pushes data to network management instead of passively waiting for the collector to query periodically. This way avoids the delay in the network transmission of query requests and the pressure brought by a large number of query requests to the network and the device, and improves monitoring performance.

The network management side and the device side of the telemetry work together to complete the overall telemetry subscription, which requires five operation steps in sequence.

(1) Telemetry configuration: Network management configures devices that support telemetry, subscribes to

data sources, and distributes them to devices.

(2) Data collection: The device collects data according to the configuration requirements of the network management.

Tab.3 Comparison between traditional and telemetry network monitoring methods

Item	Traditional OLT	Distributed architecture OLT with telemetry
Collection mode	SNMP	TELEMETRY
Collection capacity	200 pps	Above 10 kpps
Support collection purchase cycle	15 min	Millisecond
CPU occupancy under maximum acquisition capacity	About 70%	About 50%

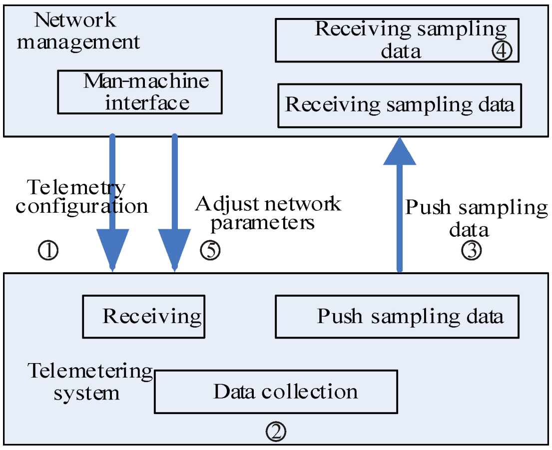

Fig.3 The whole process of telemetry

(3) Push sampling data: The device reports the collected data to the network management according to the configuration requirements of the network management.

(4) Receiving sampling data: The network management system receives sampling data, stores and displays sampling data.

(5) Adjust network parameters: Users adjust network parameters according to the sampled data and distribute them to the device. After the configuration takes effect, the new sampled data will be reported to the user. At this time, the user will analyze whether the network effect meets the expectations after the adjustment. Until the adjustment is completed, the whole traffic process forms a closed loop.

The data collected from data analysis and mining can be applied in many ways. Solutions can be obtained through data processing in network planning, assurance of the bandwidth and accurate operation.

The intelligent distributed optical access device can sense the burst characteristics of PON line traffic and user experience in real time, evaluates the high-value users of PON resources, and accurately plans the predictive capacity expansion such as 10G PON upgrade.

The network data and application data are collected and processed into large data samples of peak-to-average power ratio and experience indicators in the second cycle. The PON line expansion standard was formed through correlation analysis. On the one hand, the PON traffic burst characteristics are characterized by the ratio of second peak rate and minute average rate. Each PON port generates a large number of peak-to-average power ratio samples every day, the number of samples are 90 times more than the traditional 15 minute average rate expansion method, and peak-to-average power ratio samples are more accurate than the expansion model. On the other hand, through the correlation analysis of PON packet loss rate and application data find out the distribution law of good or bad experiences that match alignment time of peak-to-average power ratio samples, so as to determine the peak-to-average power ratio of different experience levels as the PON capacity expansion standard. Compared with the traditional capacity expansion method, which only evaluates bandwidth usage of the PON line, the peak-to-average power ratio model is associated with the application KPI, so it is more accurate.

Using the PON accurate capacity expansion standard learned from the above big data samples (such as peak average rate (*PAR*) corresponding to high-quality experience), the PON capacity corresponding to high-quality experience can be evaluated according to the total rate of PON port divided by *PAR*, and the PON resources of the current network can be accurately evaluated. Collected a large amount of data on PON traffic and accumulated a large number of effective samples, we can actively predict the PON traffic, and evaluate the PON capacity according to the total rate of PON port divided by *PAR* based on the peak-to-average power ratio capacity expansion model.

Unlike the traditional centralized OLT, distributed OLT supports the deep flow inspection (DFI) function. Introduce artificial intelligence (AI) function and use AI module to realize data mining of data package characteristics. Firstly, data mining of packet characteristics is carried out for data packets. Through continuous learning of data correspondence, data reasoning of AI can roughly distinguish typical applications such as video, online games, online education and remote office, measure different from application level indicators, and identify user application experience issues. DFI is used for application awareness. The increasingly widely used encryption transmission application, compared with the traditional deep packet inspection (DPI) scheme for parsing user interaction messages, avoids the risk of infringing on user privacy.

Each user and each service's network quality can be active perception. If network quality is poor, network management can find the problem and adjust the network quality. Poor quality problems are found and rectified before user complaining, so as to improve customer experience and satisfaction. The end-to-end network fault is accurately delimited and located, and AI is used to reduce the difficulty and complexity of problem location for the fault handler's operator. Providing accurate fault repair suggestions, the operator can quickly pick up and handle the fault. Support owner of a network to realize potential customer mining and precision marketing capabilities. Combined with all-round network endogenous data, the intelligent distributed optical access network can identify potential high-value customers. End-to-end slicing management supports the end-to-end differentiated guarantee of the network, adapts to the future oriented differentiated business development requirements and experienced business philosophy, and realizes the comprehensive bearing of a variety of high-medium-low-value services connected to the network.

In order to further implement the national action plan for coordinated development of "dual gigabit" networks, we deploy 10G PON equipment to extend from urban areas to rural areas to satisfy the rapid development of gigabit bandwidth services. At the same time, 50G PON technologies are under in-depth research and development in the future, and we hope 50G PON technology currently can be used in 10G PON equipment platform that can be directly upgraded by changing broad of 50G PON. Without buying new 50G PON OLT in the future when upgrading the network, the OLT equipment architecture of the current network cannot support 50G PON technology, resulting in cost waste in the overall replacement of OLT equipment. Therefore, future evolution technology should be considered when deploying 10G PON.

The distributed structure, to the greatest extent, can solve the problem of OLT control board switching performance and system performance caused by the increase in service board bandwidth, which is conducive to the smooth evolution of 50G PON. The single dimension improvement of broadband rate alone cannot meet the development of in-depth and diversified experience requirements, so the intelligent optical access network based on data analysis is an inevitable trend. The accuracy of data analysis is determined by the accuracy of basic data collection, and the efficiency and accuracy of basic data collection are guaranteed by telemetry technology. High precision sub second level acquisition can ensure data reliability to the greatest extent. The data is processed through DFI, intelligent analysis, and machine learning. It finally provides an important basis for network planning, ensuring bandwidth and intelligent operation and maintenance, which is conducive to intelligent network management and construction of optical access networks in the future.

Statements and Declarations

The authors declare that there are no conflicts of interest related to this article.

References

[1] ZHANG X, YANG T F, JIA X H. PON monitoring scheme using wavelength-bandwidth identification of a single fiber Bragg grating[J]. IEEE photonics technology letters, 2021, 33(8)：387-390.

[2] WANG T, LIU G. Software defined virtualized access network supporting network slicing and green communication[J]. Journal of computer research and development, 2021, 58(6)：1291-1306.

[3] ZHANG H, HAN X, WANG R Y, et al. Load balancing user association and resource allocation strategy in time and wavelength division multiplexed passive optical network and cloud radio access network joint architecture[J]. Journal of electronics & information technology, 2021, 43(9)：2672-2679.

[4] WANG J, JIA T, WANG S S. Wavelength synchronization technology for UDWDM-PON transmitter based on injection locking[J]. Chinese optics of letters, 2021, 19(1)：7-13.

[5] VARDAKAS J S, MOSCHOLIOS I D, LOGOTHETIS M D, et al. Performance analysis of OCDMA PON configuration supporting multi-rate bursty traffic with retrials and QpS differentiation[J]. Optical switching and networking, 2014, 13(7)：112-123.

[6] LIU Y, LUO F G. Generation and transmission analysis of 4-ary frequency shift keying based on dual-parallel Mach-Zehnder modulator[J]. Front edge of optoelectronics, 2017, 10(2)：160-165.

[7] LI Z Y, CHEN R, HUANG X G, et al. SVM for constellation shaped 8QAM PON system[J]. ZTE communications, 2022, 20(1)：64-71.

[8] LU Y, LIU H Y, ZHOU Q R, et al. A smooth evolution to next generation PON based on pulse position modulation[J]. IEEE photonics technology letters, 2015, 27(2)：173-176.

[9] KUMAR L S, AMARPAL S V, et al. Performance analysis for downstream next generation converged WSN-PON ODN network incorporating diverse phase delay[J]. Fiber and integrated optics, 2017, 36(1/6)：242-251.

[10] KOCHER D, KALER R S, RANDHAWA R. 50 km bidirectional FTTH transmission comparing different PON standards[J]. Optik-international journal for light and electron optics, 2013, 124(21)：5075-5078.

[11] BUTT R A, ASHRAF M W, FAHEEM M. Processing efficient frame structure for passive optical network (PON)[J]. Optical switching and networking, 2018, 30：85-92.

[12] TOSHIYUKI I, YASUHIKO N, YOICHI M. A proposal of traffic control mechanism in PON based access system[J]. Electronics & communications in Japan, Part 2, Electronics, 2007, 90(7)：41-55.

[13] RAD M M, FATHALLAH H A, RUSCH L A. Performance analysis of fiber fault PON monitoring using optical coding：SNR, SNIR, and false-alarm probability[J]. IEEE transactions on communications, 2010, 58(4)：1182-1192.

[14] MEENAKSHI C, TARAPRASAD C. A scheme for UDWDM-PON broadband access network using a mode locked laser diode and optical injection locking[J]. Journal of optical communications, 2018, 39(4)：407-412.

[15] ZHOU W, MA J X. A novel multi-band OFDMA-PON architecture using signal-to-signal beat interference cancellation receivers based on balanced detection[J]. Photonic network communications, 2016, 32(1)：54-60.