INVITED PAPER *Special Section on Optical Access System for Social Life*

Access System Virtualization for Sustainable and Agile Development

Akihiro OTAKA[†a)], ***Member***

SUMMARY This paper describes why we require access system virtualization. The purpose of access system virtualization is different from that of core network virtualization. Therefore, a specific approach should be considered such as the separation of software and hardware, interface standardization, or deep softwarization.

key words: *access system, virtualization, PON, FASA*

1. Introduction

Starting with the standardization of B-PON (Broadband Passive Optical Network) [1] in 1998, the development of optical access systems has mainly focused on achieving higher bit rates. B-PON was developed with a 155 Mb/s capacity, and the latest PON system, named NG-PON2 (Next Generation Passive Optical Network) [2], has been developed as a time and wavelength division multiplexing-passive optical network (TWDM-PON) with a 40 Gb/s capacity, namely 4 wavelengths each with a capacity of 10 Gb/s. And now the standardization of a 100-Gb/s-class PON system has begun in IEEE [3].

Today's PON market is mainly concerned with green field installation. And the domestic competition as regards broadband services means that the access network operators will install a PON system with a higher bit rate. Therefore, it appears that the trend for PON capacity development will continue for a while.

On the other hand, in countries where broadband services have reached the mature stage, such as Japan, the access system market is different. In Japan, a broadband internet access service of up to 100 Mb/s was started with a PON system in 2001. It is a very low cost best-effort type service for a massive numbers of users, and it now covers more than 94% of Japanese area [4], [5]. The growth in the number of the optical access lines is slowing down.

In the world market, this slowdown with respect to optical access lines has yet to occur. However, it will occur in the future once optical access area coverage has reached around 100%.

This paper discusses the requirements and technologies for future optical access systems in a mature market.

Manuscript received May 15, 2017.
Manuscript revised August 8, 2017.
Manuscript publicized October 18, 2017.

[†]The author is with NTT Access Netwrok Service Systems Labs., Yokosuka-shi, 239-0847 Japan.
a) E-mail: ootaka.akihiro@lab.ntt.co.jp

DOI: 10.1587/transcom.2017OAI0003

2. Requirements for Future Access Systems

2.1 Sustainable Development

For access network operators, it is common to install the latest standard system at the first stage of PON installation. This is to appeal to consumers by announcing that they can offer much more capacity in the access network than other operators, and thus gain more market share during area expansion. In Japan, the installation of Asymmetric Digital Subscriber Line (ADSL) services was an example of such speed competition, and systems were installed with the latest standard. From 2000 to 2004, the speed of ADSL services increased from 1.5 Mb/s to 47 Mb/s [6].

When the possibility of green field development is exhausted, the competition will shift from area expansion to the acquisition of new users in the existing field. Access network operators aim to realize efficient network operation by improving PON utilization. Therefore, the motivation for installing the latest standard system will decrease during this stage. And for the fiber to the home (FTTH) service, the traffic generated by typical users is extremely low compared with the capacity of the access system. Figure 1 shows the progress made on PON standards and the average traffic of each user in Japan. The average user traffic is calculated from the total internet traffic and the number of optical access users in Japan [7]. Note that the total internet traffic includes that of ADSL and CATV (Community Antenna Television) services, so the average user traffic value is overestimated. And the top 1% and 5% traffic of heavy users is calculated from the user distribution reported by IIJ [8]. Even for the top 1% users, less than 1/1000 of the bandwidth provided by

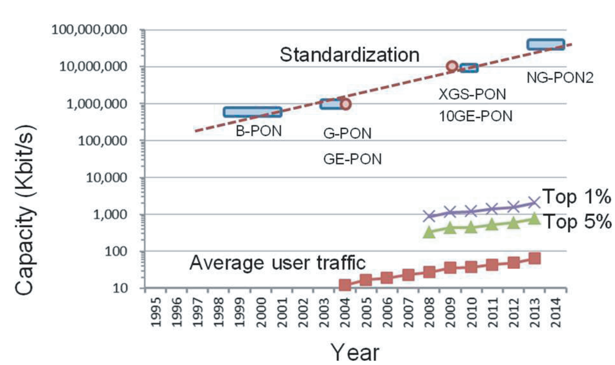

Fig. 1 Progress of PON standardization and user traffic trends.

the access system is used. Note that the traffic in the busiest hour is around 2 to 5 times more than the average. Hourly fluctuations do not affect this discussion. Therefore, very few users will find the latest system with more bandwidth attractive, and so there may be very few who will change to a higher bit rate access service. This means that these users are not dense enough geographically for PON to be applied.

When FTTH services are in the mature stage, neither operator nor user will have any intention to switch the access line to the latest system if there are no new services that require a high speed such as 4K/8K video distribution. Their main concern will be how to keep the system and the service continuously available.

The speed with which FTTH installation progresses varies from region to region. The Japanese market has now reached the mature stage and FTTH systems are in the maintenance phase. On the other hand, the Chinese market is now in the growth stage [9], and the system is in the installation phase. In this situation, it seems that the Chinese market is attractive for equipment manufacturers and application specific integration circuit (ASIC) manufacturers, so they seem to focus on the development of new systems, not the maintenance of legacy systems. This makes it difficult for the operators in mature stage to maintain legacy existing systems and services.

This is the first issue for operators involved in the mature FTTH stage.

2.2 Agile Development

In the FTTH growth stage, the rapid installation of the system is much more important than the variety of services. So it is common to install a uniform system. On the other hand, in the mature stage, it is necessary to provide various kinds of services in order to acquire new users. In 2015, NTT announced that it was shifting its service strategy from the business to consumers (B2C) model to the business to business to consumers (B2B2C) model, namely a collaboration model [10]. In the early stage of the FTTH deployment, NTT itself sold access services directly to the consumers in a B2C manner. Now NTT is going to provide access lines to its business partners who will provide network and information technology (IT) services in a B2B2C manner. This means that NTT will design the network services to meet the requirements of various kinds of partners.

This strategy will lead to system diversification. The access network operator must have a small number of various kinds of access systems.

Today's access systems have been developed for specific services such as FTTH, video distribution, and business-related virtual private network (VPN) services. The functionalities are implemented differently for each system and by each manufacturer. Therefore, functions cannot be added or changed flexibly. FTTH is a simple service that has been widely installed in the field. A typical FTTH system has only simple functions and it is usually impossible to add all the functions needed for B2B2C. For example, the typical FTTH system does not have bandwidth control function that supports multiple algorithms as shown in 3.2, because it has been developed just for the Internet access services. And it usually does not have enough resources to support all functions.

Moreover, a system with all the necessary functions is expensive. It is not realistic for an access network operator to install a new comprehensive system in advance that will meet all future requirements. The installation of unnecessary functions leads to a high cost, and the operator cannot know all the functions that will be necessary in the future.

This is the second issue with respect to future access system flexibility.

3. Solutions with Software Defined Technologies

Along with the development of server virtualization technologies, Software Defined Network (SDN) technologies have also been developed mainly to realize a flexible network configuration in data centers [11]. And the application of these SDN technologies to operators' networks is being discussed.

In a fixed access network, the users and the central office are connected by physical wiring, so it is unsuitable simply to employ SDN technologies for flexible connection between users and central offices. For the access network, the ONF R-CORD project is developing the technologies to realize the flexible network configuration inside the central office [12]. And to solve the issues mentioned above, we need technologies not only for the flexible configuration but also that for the flexible modification and addition of the functions on the access system. SDN technologies must be extended.

3.1 Flexible Access System Architecture; FASA

NTT proposed the Flexible Access System Architecture (FASA) concept as a solution for the problem of future access [13], [14]. Figure 2 shows a schematic view of the concept. To make it possible to add and change functions in access systems, the functions necessary for access are modularized into small components and combined on a general platform.

The distinctive feature of the FASA is that it selectively uses parts realized by software and those realized by hardware according to their characteristics. In Internet Protocol (IP) core networks, conventional servers, routers and switches use Ethernet communication. Therefore, the conventional servers and the white-box switches with Ethernet can be used with the add-on software. On the other hand, access systems should support both an Ethernet frame and an EPON (Ethernet Passive Optical Network) frame [15], a GEM (General Encapsulation Method) frame [16], a DSL frame [17], an ATM (Asynchronous Transfer Mode) cell [18] and so on, depending on the geographic user density, and the transmission distance. Such frame processing needs a high speed and a wire rate. So it is difficult to implement as application software that runs on conventional central pro-

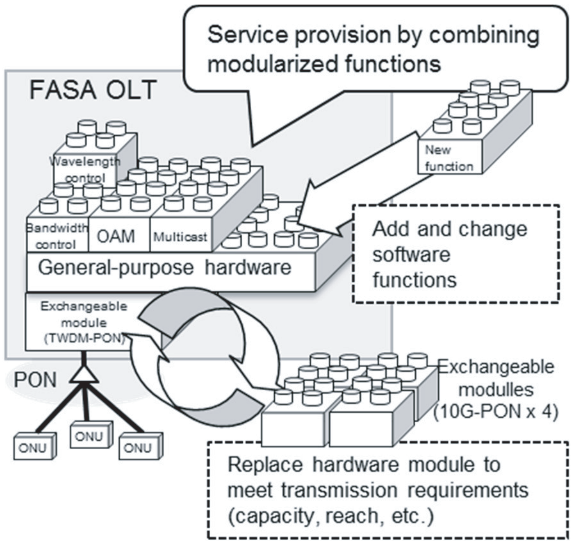

Fig. 2 FASA concept.

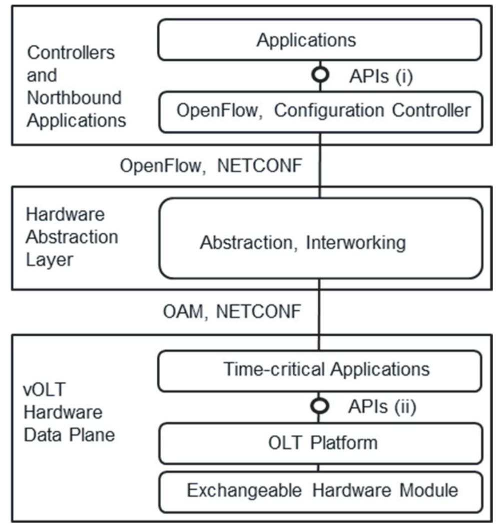

Fig. 3 Architecture of virtual access system.

cessing units (CPUs) and operating systems (OSs). In the FASA concept, the functions that require high-speed processing are implemented as exchangeable hardware modules, such as with ASIC, and the modules will be replaced on a general-purpose platform. This achieves a flexible change in the high-speed frame processing functions. And it also independently upgrades the platform and the hardware module. On the other hand, the conventional equipment is implemented as one box or one board that contains ASIC, CPU, OS and firmware as a monolithic manner, so everything must be modified simultaneously if required.

The functions, which do not require high-speed processing, are implemented as an application on the platform. The applications run on a conventional CPU of the server or a white box switch platform. And the applications that do not require frequent processing can be implemented on cloud servers in an aggregated manner, thereby improving the efficiency of the equipment and operation.

With the FASA concept, the following can be achieved;

(i) Rapid development, by adding and changing access functions.
(ii) The hardware platform realizes common spare parts and common maintenance procedure.
(iii) CAPEX reduction using common hardware.
(iv) The platform hardware can be upgraded independently of the access functions; therefore the sustainable development of the access system can be achieved. (The sustainable development of the hardware module will be discussed in 3.3.)

3.2 FASA API

To realize the FASA concept, it is necessary to clearly define the Application Programming Interface (API) for the combination of software functions. The API supports the optical line terminal (OLT) configuration, and provides control and monitoring as well as communication with the optical network unit (ONU) through the OLT. The Broadband Forum (BBF) is now developing the architecture and the interfaces of these functional blocks. These on-going discussions of virtual OLT hardware abstraction (vOLT-HA) and the YANG model [19] of the access system are complementary to the FASA concept, so FASA has been proposed to the BBF and standardization discussions have already started.

Figure 3 shows the virtualized access system architecture discussed in the BBF [20]. The following two types of APIs should be developed.

(i) Hardware abstraction interfaces, on which access function applications run on an SDN controller.
(ii) The interface on the OLT hardware, on which time critical applications run.

And the FASA platform has functions that realize application chaining and exchange management.

The first type of API is typically on the SDN controller. It is used for abstracting the hardware and the access protocols. Through these APIs, the access system can be configured with OpenFlow [21] and NETCONF [22]. These interfaces also support alarm monitoring and status reports from the access system. This first API is essential for the SDN technology to realize the flexible network configuration.

The second type of API is typically on the OLT hardware. It is used for running time-critical applications such as bandwidth and QoS control. Note that the time-critical applications have their own algorithms, and these are also configured through the first type of API. This second type API is distinctive for FASA.

For example, there are some types of dynamic bandwidth allocation (DBA) algorithm for the upstream traffic control of a PON system; fixed bandwidth allocation for each ONU, fair bandwidth allocation, and mobile scheduler synchronized bandwidth allocation. To realize these algorithms, we need to develop different types of applications. Figure 4 shows the features of these DBA techniques. Fixed band-

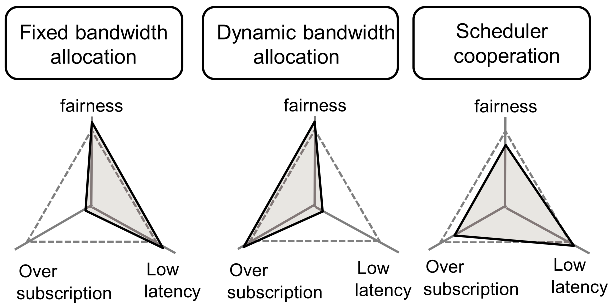

Fig. 4 Feature of DBA algorithms.

width allocation is typically employed for the business use for example with leased lines. It does not use status reports from ONUs, and so it achieves low latency. The second type is typically employed for internet access use with best-effort type service conditions. With this algorithm, the bandwidth for each ONU is calculated dynamically based on status reports (bandwidth allocation request) from the ONUs. With this algorithm, a certain amount of delay must occur such as that caused by report gathering, calculation and sending the access permissions for each ONU. However, it achieves high bandwidth efficiency. The third type of DBA is mainly proposed for mobile fronthaul [14]. With this algorithm, the PON and mobile schedulers cooperate and the allocated upstream timing of a PON system is calculated based on the upstream timing allocated for the mobile terminals. This requires scheduler cooperation functions on both the PON and mobile system, and it achieves both a low latency and high bandwidth efficiency.

In this way, by making the control algorithm exchangeable, we can achieve high flexibility. And there are the other functions that must also be exchangeable, namely the sleep control and the protection control.

3.3 Exchangeable Hardware Module

Exchangeable hardware modules allow us to realize the sustainable development and flexibility of the platform. On the other hand, the modules are typically composed of ASICs. It is difficult to realize the same low-layer functions as software that runs on a standard CPU and OS, because the low-layer functions require high-speed wire-rate processing and also require a supporting special transmission-frame structure. For example, the transmission frame building and parsing for the PON protocol are not supported by the ordinary network interface card (NIC) used for standard servers and white box switches, because they only support Ethernet. Therefore, the sustainable development of the hardware modules themselves is not realized in this architecture. We already face the risk of discontinued manufacturing of ASICs in the future.

To achieve the sustainable development of hardware modules, the functions that require wire-rate processing, such as the physical and media access control (MAC) layers, should also be implemented as programs on a generic device. There are some challenges for the software implementation of low layers. For example, the high-speed software implementation technologies for forward error correction (FEC), and encryption functions with a 10-Gb/s-class processing rate have been reported [23]. And the real-time processing of the Multi-Point media access control protocol (MPCP) of EPON as application software on a standard server has also been reported [24]. In addition, as the next step, the utilization of programmable devices, is expected such as a field programmable gate array (FPGA) and a general purpose graphic processing unit (GP-GPU) to support a special transmission frame structure for exchangeable hardware modules.

These are the challenges that face the service continuity using existing access systems and protocols. In the future, it will be necessary to develop a new protocol that does not require special hardware devices. This means the protocol must be able to run on generic devices that are distributed in large quantities for general purposes, such as Ethernet PHY and MAC devices.

Note that this discussion is not only for OLTs. ONU softwarization will realize a built-in ONU in a gateway. The access operators can provide an ONU box as before, and can also provide them to the gateway manufacturers under a software license. This software ONU will extend the range of the gateway and the use of optical access lines.

3.4 Migration from Legacy

With access system virtualization, it is possible to intensively and flexibly manage the connection configuration of the core network side of an OLT in the same way as that discussed for SDNs [12]. For example, the virtual local area network (VLAN) configuration of each ONU and/or of each service can be flexibly changed and managed. And it is also possible to realize VLAN path protection using these flexible-configuration controls combined with alarms and monitoring.

As is well known, in the current situation network operators commonly install systems that automatically configure OLTs, switches and routers based on the customers' service orders. This means that primitive automatic flow-through operations have been realized. The existing flow-through system has functions for facility management, inventory management, network configuration management, creating and applying configuration and so on. The flow-through operations are realized in cooperation with these various functions. However, in the current systems, the network equipment interfaces vary depending on such factors as the manufacturer, device type, and software version. Therefore, to change to the new service condition requires a new equipment configuration and new parameters, and to change the equipment itself to the new hardware version requires the large-scale development of various systems. It is not realistic to provide multiple types of small-scale services.

This issue will be solved with the SDN technologies, when the interfaces between the network equipment and controller, and between the controller and the north-side operation systems are standardized. And the SDN technologies will also realize additional services such as edge computing, content caching, and virtual customer premise equipment (vCPE) by employing servers located around the access network [12]. It will be also possible to provide these functions on the OLT itself if the OLT platform has surplus CPU and memory resources.

In terms of realizing this extended SDN based access network, it is not realistic to replace all the already installed access equipment and systems. In the access network, introducing SDN technologies in an overlay method as with the core network does not solve the above problems. Therefore, the most difficult issue is how to install SDN technologies so that they can coexist with large numbers of existing systems.

One idea is to install a new system simply for a new service. The systems will be completely separate for new and existing services. Another idea is to install new network equipment to replace existing equipment that is close to the end of its lifetime. The installation method depends on the circumstances of the network operator and the existing systems, so it cannot be unequivocally specified. In any case, the installation and replacement must be undertaken in a part-by-part manner to achieve a smooth and easy update. Therefore, the standardization of the interfaces between each disaggregated functions and their abstraction are key technologies for future access systems. This disaggregation discussion is similar to the FASA concept for access equipment virtualization.

4. Conclusion

Without access virtualization technologies, the access system cannot develop beyond the mature stage. In the mature stage, the access service will be diversified, and current access systems do not support the flexible addition and change of functions. It is not realistic to continuously install new equipment to meet new service demands in the future. And there is a risk of the discontinued manufacturing of ASICs. In these situations, the network operators have to consider how to maintain their current services continuously and how to keep developing their new access services continuously in the future.

This paper described access virtualization technologies including FASA. With these technologies, the functions of the access system are disaggregated into small parts and combined with each other with standardized interfaces. This realizes the sustainable and agile development of both the access equipment and the controllers.

And further study is needed as regards the operation systems for SDNs. This paper also showed that the concept of disaggregation and combined with the standardized interface must be expanded to all operating systems to allow smooth migration from the legacy network in the future.

References

[1] ITU-T Recommendation G.983
[2] ITU-T Recommendation G.989
[3] IEEE P802.3ca 100G-EPON Task Force, http://www.ieee802.org/3/ca/index.shtml
[4] Information NTT-East 2016, p.72, https://www.ntt-east.co.jp/databook/pdf/2016_allpage.pdf
[5] Data Book NTT-West 2016, P.46, http://www.ntt-west.co.jp/info/databook/
[6] H. Esaki, H. Sunahara, J. Murai, ed., Broadband Internet Deployment in Japan, pp.78–105, Ohmusha, Tokyo, Japan, 2008.
[7] Ministry of Internal Affairs and Communications, "Aggregation and Provisional Calculation of Internet Traffic in Japan," Press Release, Feb. 2017, http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/170207_1.html
[8] K. Cho, "Broadband traffic report," Internet Infrastructure Review, vol.24, pp.28–33, Aug. 2014.
[9] TCA telecom data book 2016, http://www.tca.or.jp/databook/
[10] NTT News release, "Hikari Collaboration Model – Contributing to the Creation of New Value –," May 2014, http://www.ntt.co.jp/news2014/1405eznv/ndyb140513d_01.html
[11] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Lexford, S. Shenker, and J. Turner, "OpenFlow: Enabling innovation in campus networks," ACM SIGCOMM Comput. Commun. Rev., vol.38, no.2, pp.69–74, 2008.
[12] Residential CORD, https://wiki.opencord.org/display/CORD/Residential+CORD
[13] FASA white papers Ver. 1.0 and 2.0, http://www.ansl.ntt.co.jp/e/global/FASA/index.html
[14] A. Otaka, "Flexible Access System Architecture: FASA," NTT Technical Review, vol.15, no.4, April 2017, https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201704fa5.html
[15] IEEE Std 802.3-2015
[16] ITU-T Recommendation G.984.3
[17] ITU-T Recommendation G.992.1
[18] ITU-T Recommendation I.361
[19] IETF RFC 6991
[20] Broadband forum working text WT-384, "Cloud Central Office Reference Architectural Framework."
[21] OepnFlow Switch specification, https://www.opennetworking.org/sdn-resources/technical-library
[22] IETF RFC 4741
[23] T. Suzuki, S.-Y. Kim, J.-I. Kani, K.-I. Suzuki, A. Otaka, and T. Hanawa, "Parallelization of cipher algorithm on CPU/GPU for real-time software-defined access network," Proc. APSIPA Annual Summit and Conference 2015, pp.484–487, Dec. 2015.
[24] M. Tadokoro, K. Nishimoto, T. Mochida, T. Tanaka, T. Yamada, A. Takeda, and T. Inoue, "Design of softwarized EPON OLT and its transmission jitter suppression techniques over MPCP," Proc. OFC 2017, paper W2A.28, 2017.

Akihiro Otaka received the B.S. and M.S. in physics from the University of Tokyo in 1989 and 1991, respectively. He joined NTT in 1991and engaged in developing optical lithography technologies for LSI fabrication. In 1998, he began working on the development and standardization of optical access systems such as Gigabit and 10 Gigabit EPON. From 2010 to 2014, he was with NTT EAST R& D Center, where he worked on optical access, wireless access, and wireless home networks. He joined NTT Access Network Service Systems Laboratories in 2014. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE), Japan, and the Japan Society of Applied Physics (JSAP).