Compatibility of Heterogeneous Devices Based on 2.5GBase-T

So-Ki Jung
Infra Innovation Team
SKBroadband
Seoul City, Republic of Korea
mkgg0107@naver.com

***Abstract*—**This paper proposes a technology that provides automatic link options for mutual compatibility among devices from different chip vendors. Many different vendors manufacture chips, which often require interconnections with existing Internet services, and the different data transmission environments limit the connectivity between devices. Consequently, the Internet quality of service drops below the standard expected by subscribers. The proposed technology secures a compatibility between devices related to high-speed data transmission. More specifically, even when devices that are inter-connected via cables are in different data transmission environments, at least one optimized link connection is set up between devices to ensure compatibility between new and existing devices.

Keywords—Automatic link; Devices; Heterogeneous; ONU; Optimized link

I. INTRODUCTION

Recently, the use of wired/wireless communication services has increased in various industries, including big data, massive content service, smart devices, and virtual reality. Accordingly, devices that are designed for a wired/wireless network should be upgraded to incorporate a variety of services from different user perspectives. With an increase in the quantity of data transferred over many different networks, and because the day-to-busy-hour ratio is high, one of the main concerns is to prevent the occurrence of signal delays [1]. Transmission delays result from as the network capacity is exceeded owing to the high usage rates of unquantified data and media between wired and wireless service users [2]. According to one report by Cisco, it is predicted that traffic loads will increase by up to 24% each year on average, and it is expected to triple by 2021 compared to the current levels [2]. As data traffic increases drastically, it is necessary to develop software-based solutions that enable flexible operations of various industrial environments and communication networks, rather than making continuous attempts at increasing the network capacity [2].

Considering the expected increase of wired/wireless communication traffic, the Ministry of Science and ICT has conducted the Giga Internet establishment and promotion project from 2009 to 2017. The Giga Internet project is a national project that was planned in preparation for the 4th Industrial Reform, which anticipates a drastic traffic increase. In this regard, the governmental R&D project aimed to develop a Giga-speed network as well as related devices to meet customers' increasing demands for data bandwidth. For network advancement, various Giga-device solutions had to be developed, and existing network environments also had to provide service to both existing and newly developed synchronous payload environments (SPEs). In existing network environments, data-transfer conditions between devices were different, with no mutual compatibility guaranteed. As a result, the transmission quality was likely to deteriorate. Besides, link connection settings may be limited owing to differences between chip vendors as well as data-transmission definitions. As customers adopt new Giga services to their existing devices, operators should set up the link speed manually. As the link speed and communication mode (full duplex/half duplex) are different, data-transmission environments also differ accordingly. In addition, when the transmission network quality decreases, the operator needs to set it up manually. Because the standard link speed is the only option for the manual setting, the service quality is likely to be lower than that of the Internet service to which the customers subscribed. Therefore, it is necessary to secure a device-to-CPE link transfer (auto-negotiation) for new service products so that a suitable level of transmission network quality can be maintained between the CPE and devices.

This study assumes that the service speed between the CPE and Internet transmission devices, whether new or existing, is less than 2.5Gbps. For such service products whose speed is less than 2.5Gbps, at least one optimized link speed is to be set up automatically between both standardized and non-standardized devices, even in different data-transmission environments so that compatibility can be guaranteed among service products with different speeds. Of the existing transmission service types, only those whose lines are 2Pair UTP, 4Pair UTP, etc., will be applied. Every technology application is practiced with reference to the existing standardized technology bases at home and abroad. In order to address the problem of compatibility between standardized and non-standardized CPE units at home and abroad, technological developments were realized in collaboration with the SK Telecom Network Technology Institute and HFR, and a patent application has been made. This research is part of the governmental R&D project on Giga Internet establishment and promotion, which is conducted by the Future Ministry. This paper consists of the following sections: Section 2 presents a summary of the Giga Internet establishment and new technology development. Chapter 3 describes the experiment conducted to develop Giga Internet technology. Finally, Chapter 4 concludes this study and presents the direction of future study.

II. Giga Internet Establishment and New Technology Development

With respect to Broadband Internet services, the speed has increased from 27.5 Mbps to 53 Mbps, and the proportion of video watching on the entire Internet traffic has increased from 73% to 82%. It is expected that by 2010, domestic Internet traffic will be 2.3 times more than that in 2016, and that the proportion of video traffic on the entire Internet will increase from 59% in 2016 to 77% by 2021[2]. Accordingly, there have been continuous improvements in passive optical devices (PONs), which are used for the transmission of optical Internet signals into customers' residences[3]. Figure 1 shows the process of technical advancement of devices through which optical services are provided at customers' residences as Internet traffic increases [4]. Because the technology behind advanced optical devices (PONs) and Giga network service is extensive, various organizations have tried to lobby for standardization. For example, recently, Giga solution technologies, such as “G.Fast,” have been developed and standardized using NG-PON2[1], XG-PON, 2.5G Ethernet, and phone lines. Figure 1 illustrates the technical advancement of the 2.5G Ethernet solution and the initial steps of the current technology. The 2.5G technology interlinks the 1 Gbps and 10 Gbps technologies. This solution provides service using existing UTP [2] Cat5e cables and the NBase-T Ethernet technology [5].

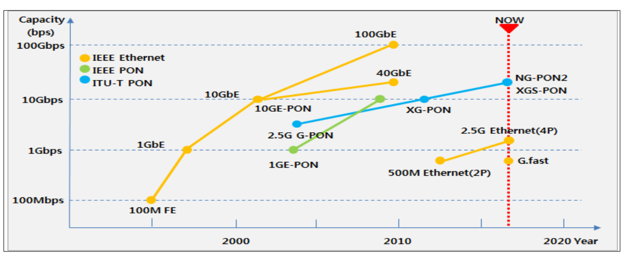

Fig. 1. Evolution of PON technology depending on increased traffic.

Figure 2 shows a diagram of network services for apartments and private houses that utilize local area network (LAN) cables, phone lines, or coaxial cables. Recently built apartments provide fiber-to-the-home (FTTH) services that utilize optical cables for Internet connections into each customer's residence. However, apartments that are 20 years old or even older, as well as rental apartments, utilize vertical ducts only. In particular, apartments with corridor access have no horizontal duct system, and there is therefore the need for drilling between adjacent apartment units to run cabling. Therefore, LAN or optical cables need to be installed on the outer walls of apartments in order to make Internet service available. When LAN cables are utilized, Internet services may be provided according to the type of product, such as 2Pair UTP and 4Pair UTP. The ONU[3] network utilizes optical cables to transmit OLT and upper/lower signals from a communication station. OLT options include G-PON and E-PON, depending on the access mode, and this study adopts the G-PON service mode.

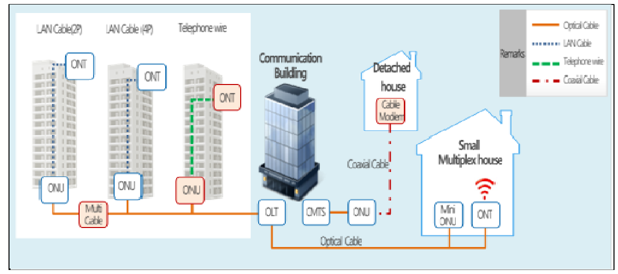

Fig. 2. Overview of the Internet service in apartment houses and single houses.

Figure 3 shows the scope of the ONU and CPE development on the basis of 802.3bz, which is Ethernet copper technology for Giga Internet services. The Giga Internet service connects OLTs at a communication station to ONUs via optical cables and connectors, and ONUs interlink with the CPE in each customer's residence using optical or UTP cables in order to provide Giga Internet service. However, with respect to ONUs and CPE devices (ONTs), standardized IEEE 802.3bz devices and non-standardized (2Pair 1G) products are used. Thus, standardized and non-standardized devices can perform link speed mapping automatically depending on the customer's service type. For ONUs and CPE that support multiple transmission speed options, priorities of data-transfer speed between the ONU and CPE are to be determined. The link order of devices is decided automatically on the physical layer in order to form a data link layer between Ethernet CPE units. The hierarchy consists of a data link called the media access control (MAC), and a physical measurement called the physical coding sublayer (PCS) as the OSI 7 layer is selected for the ONU Giga Ethernet [7].

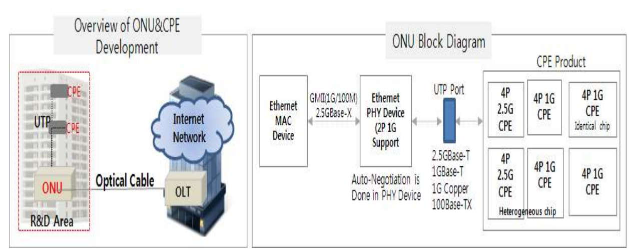

Fig. 3. Development scope of 4Pair 2.5G and ONU block diagram

[1] NG-PON2 (Next-generation passive optical network): is a next-generation PON technology that secures a broader bandwidth[5].

[2] UTP(Unshielded twisted-pair cable): LAN cable that transmits large-capacity information with minimum inter-cable interference[6].

[3] ONU (optical network unit): An integrated switch device that provides customers with voice, data, and video services[10].

Table 1 compares 1G and 2.5G services. IEEE 802.3ab and IEEE 802.3bz provide 1000BASE-T and 2.5/5GBase-T for transmission speed options. The UTP mode of the physical layer of IEEE 802.3bz makes available 2.5Gbps and 5Gbps communication speed options for Cat 5 and Cat 6, respectively. ONUs and CPE units utilize the Giga media independent interface (GMII) and universal serial XGMII (USXGMII) as the transmission interface in such a way like the UTP connection to the data transfer link layer MAC and the physical transmission technology layer (PHY) [8]. For IEEE 802.3bz standardization, the physical transmission layer (PHY: Physical layer) may be defined specifically for 10GBase-T technology. As the signal ratio of 10Gbase-T technology is set to 1/4 and 1/2 by clock scaling, the transmission speed reduces to 2.5–5 Gbit. As the signal bandwidth decreases, the number of cable requirements decreases accordingly. Therefore, for 2.5/5 GBase-T, the Cat 5e or Cat 6 cable length should be within 100 m[9]. With respect to 2Pair 1GBase-T, the transmission distance with no cable interference in each channel is about 62.5 m, and for 4Pair 2.5GBase-T, it is about 100 m. There may be a difference in number of transmission bits per channel. 2.5GBase-T technology is superior and considers the pulse-amplitude between two units. The modulation system corrects errors using PAM-5 and PAM-16-based low-density parity checks in a noise transmission channel.

Table Ⅰ. Comparison of 1GBase-T & 2.5GBase-T[8][9]

Article	IEEE 802.3ab	IEEE 802.3bz
Data Rate	1,000 Mbit/s	2,500 Mbit/s
Chip Vendor	Broadcom, Marvell, others	Broadcom, Aquantia, Marvell
Number of Transmission Channels	4	4
Each Channel's Transmission bits/s/Hz (bits per symbol * 2)	4	6.25
Cable Nyquist Rate per Channel	62.5 M	100 M/200 M
FEC	LDPC Error Correction	LDPC Error Correction
Cable Specifications	Cat 5e, 2Pair	Cat 5e/Cat6,4Pair
UTP Cable Maximum Frequency	100 MHz	100 MHz
Modulation Mode	PAM-5 (pulse amplitude modulation)	PAM-16
MAC & MDI (physical) Interface	SGMII (Serial Gigabit Media Independent Interface), 10M/100M/1000 Base-T supported	USXGMII: Universal Serial XGMII, 10M/100M/1G/2.5G/5 G/10GBase-T

Table 2 shows how a telecommunication service operator performs downshift provisioning using the program to connect the customer's line to a suitable network. Specifically, ONU and CPE units that are connected to each downlink as well as downlinks themselves can perform downshifts automatically using the auto-negotiation function. The “downshift” connects links having different speeds, such as 4Pair-2.5G, 2Pair-1G, 2Pair-500M, and 100M, to an ONU port. This function may generate Syslog if a customer's line is connected to a heterogeneous link owing to quality deterioration. For instance, in the event where a customer's line is set by a telecommunication service operator to 2.5G Internet speed, but its quality deteriorates, the link may be set to 2Pair 1G having a different speed with the Syslog generated. In the event that a customer subscribes to a 100 Mbps Internet line and opens 2Pair CPE, the ONU should set up 100 Mbps speed automatically. This function is to prevent the link from being connected to a 500 Mbps line when this type of condition is not defined. If there is a setting in a device monitoring system that indicates that the downlink is connected to a 2Pair 1G customer, 2Pair 1G service is provided automatically, even if the 4Pair 2.5G CPE unit is detected

Table Ⅱ. 4Pair 2.5G downlink that supports the downshift function [3].

Article	Port Provisioning	Order of Auto Downshift
4Pair 2.5G	4Pair 2.5G	4pair-2.5G→4pair-1G→ 2pair-1G→2pair-100M
	2Pair 1G	4pair-1G→2pair-1G→ 2pair-100M

The previous section specifies items and operation principles of 4Pair 2.5G technology development. The following section presents results of the automatic link-setting experiment with downshift applied between the ONU and CPE units.

III. Experiment with New Giga-Internet Technology

Figure 4 shows the ONU components, which include environment management, link-support management, vertical environment management, and compatibility management. Among these, the link-support management part determines one of the link speed candidates, including standardized and non-standardized link speed options of CPE[4] units once the data-transfer environment is confirmed by the environment management part. All of the link speed options that are available in the data-transmission environments of ONUs are grouped as candidates, and one of them is chosen. The ONU environment management part checks the ONU data-transfer environment based on the cable link type and speed. The vertical environment management part focuses on managing the comprehensive vertical section environment related to the vertical hook-up devices that are connected via cables. As Giga Internet service has become available in addition to conventional Internet service using existing infrastructure, various manufacturers have produced chips for CPE devices in order to enable support for data transmission with ONUs. As a result, it is often the case that such different chips of devices

[4] CPE (customer premises equipment): A device used to transmit a large quantity of data from ONU devices to service media[12].

are not compatible with the general communication environment. Owing to the difference between ONUs and CPE chips, there are fewer available link-connection options. When ONUs are used to support the data transmission of CPE units, the CPE units determine the order of the link connection based on the vertical data-transfer environments that are supported by the embedded chips. Once the ONU compatibility management part completes the detection of link speed candidates of the CPE, it checks their supported link speed candidates and excludes non-standardized link speed options that are not supported. In other words, with the exception of standardized link speed options, the remaining link speed candidates are inspected to determine whether they may be connected to the CPE, and the compatibility-management part then determines the order of the link connection by arranging options in the order of link speed. Even if devices that are connected between the ONU and CPE via a cable are in different data-transfer environments, at least one link connection that is optimized between devices is configured automatically. An experiment should be conducted to confirm whether mutual compatibility is guaranteed, regardless of the data transmission environments in specific conditions where high-speed data service is available using an existing communication network. The ONU checks the data-transfer environments based on the link types and the available maximum link speed of the transmission channel(s). There may be more than one type, depending on the type of UTP cable link and the maximum link speed.

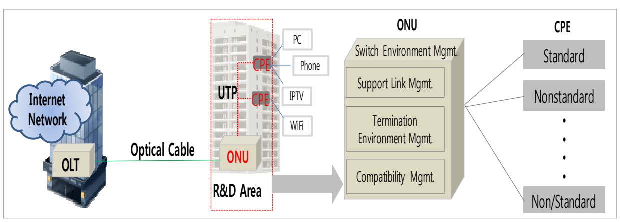

Figure 4. Auto link connection structure [3]

Figure 5 shows the work flow used to determine the order of the link connection between devices more precisely. ① shows the case where the vertical ONU adopts a chip that is manufactured by a specific company (company A). In other words, the standard 1 link-type speed (4Pair 2.5G) is supported when the ONU's data-transmission environment is set as the standard. With supported link speed options checked, the order of the link connection is determined. The order of the link connection is determined from among the subscribers' service products as follows: 4P-2.5G→4P-1G→2P-1G→2P-100M. Figure 8 ② shows the second vertical data-transmission environment, which supports non-standardized devices. As illustrated in Figure 4 with respect to the transmission environment (non-standardized) of the second CPE data, the order of the link connection is for the case where the vertical repeater equipment is not yet connected to the standard link speed option. Figure 8 ③ and ④ show how the CPE determines the order of the connection based on the speed of standard-supporting vertical devices, rather than that of the manufacturers stated in ① and ②. Meanwhile, ⑤ and ⑥ show how to support the non-standardized link speed when the CPE is in the conditions shown in ③ and ④.

Table Ⅲ. 4Pair 2.5G downlink that supports the downshift function [3].

Article	Downlink	Detailed Explanation
ONU	Ports 1-8: 1000Base-T Ports 9-24: 2.5GBase-T	Switching conditions upon connection with each vendor's CPE Downlink 1G-TX, 2.5G-TX Downshift motion check 4Pair/2Pair1
CPE	WAN: 2.5GBase-T LAN: 1000Base-t*4	

Table 3 shows the results of the in-situ experiment of ONU and CPE devices. ONUs are classified as 1000Base-T and

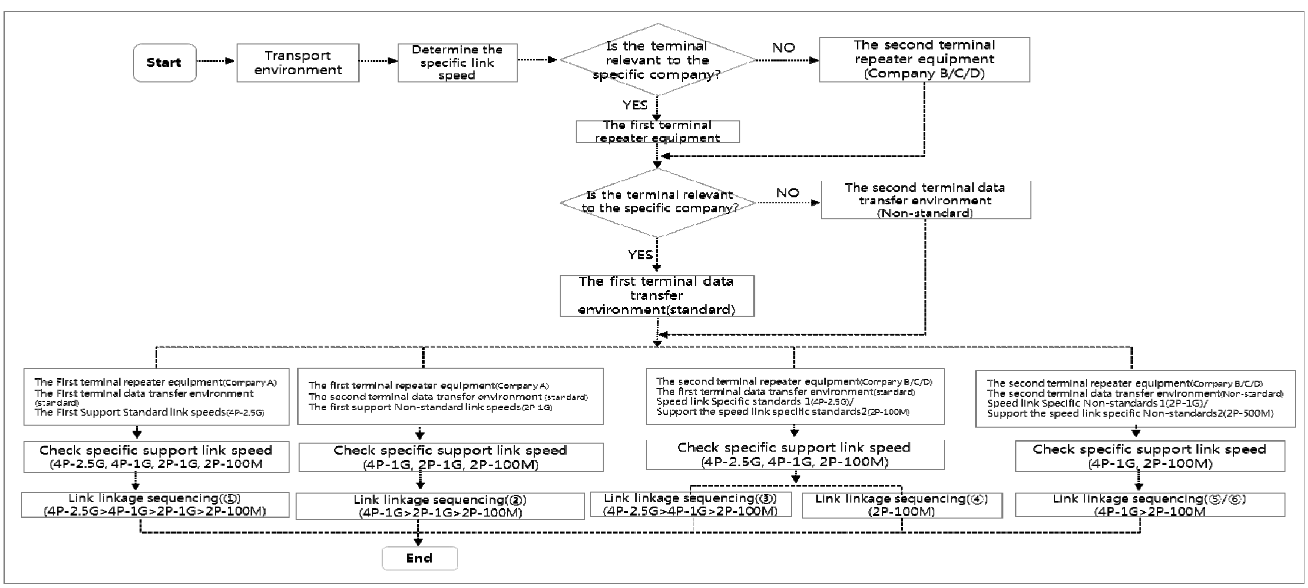

Figure 5. link linkage sequencing process

2.5GBase-T from among 24 ports. Ports 1 to 8 are commonly used for 1GBase-T, while ports 9 to 24 are used for 2.5GBase-T in the link-down test. The WAN speed of the CPE is set to 2.5G, and the LAN is set to 1G*4. With respect to the downshift, 4Pair and 2Pair are applied while the motions are checked.

Figure 6-7 illustrates the case in which a downshift link is configured for various ONU and CPE chip vendors. ONUs rely on chip manufacturers such as Broadcom & Aquantia. For each of the six CPE types, the figure illustrates the link setting steps in environments where 4Pair and 2Pair UTPs have been installed. ONUs support a maximum 1G link speed (2P 1G) using the 2Pair link-type cable. Chips that are manufactured by specific companies are installed. The figure illustrates the process of determining the order of the link connection based on the general vertical data-transfer environments. When chips that are manufactured by another company are installed on the ONU, the order of the link connection is determined in the same manner. The ONU arranges standardized link speed options (4P 2.5G→4P 1G→2P 1G→2P 500M→2P 100M) in the order of link speed fast sequence.

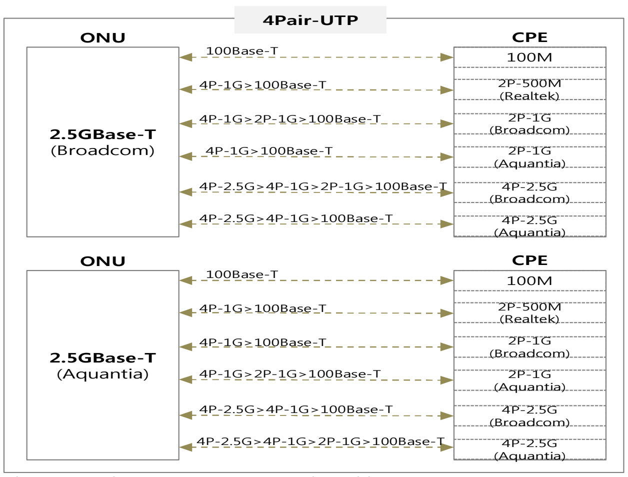

Figure 6. 4Pair 2.5GBase-T IoP Mapping table.

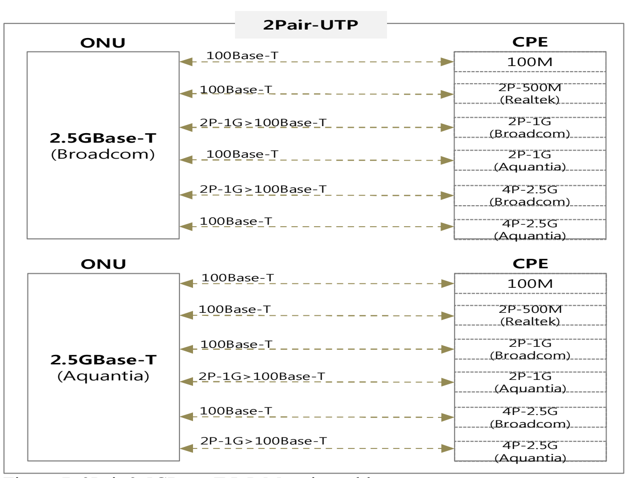

Figure 7. 2Pair 2.5GBase-T IoP Mapping table.

Figure 8 show a Network configuration in which speed measurements are made for customers using 2.5Giga internet services. Speed measures the internet speeds of subscribers to the Cat5 4Pair section.

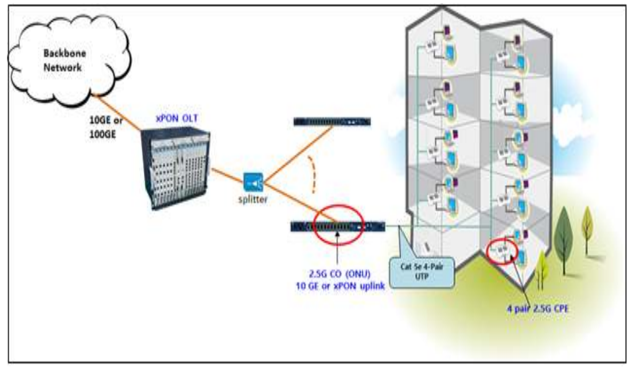

Fig 8. Test range is from ONU to CPE

Table 4 shows the test results from ONU to CPE. Measurement of the time scale at which the instrument will data traffic forwarding after the link is established. Measurement of the time reference taken by the instrument after setting up the link data traffic forwarding

TableⅣ. 4Pair/2Pair 2.5Gbps speed experiment results

2.5G Speed – 4Pair Cable			
CPE WAN	CPE Model	Real Link	Link Time
100M	D firm	100M	3.21
4P-1G	M firm	1G	3.69
2P 500M	H614G	1G	4
2P 1G	H355A	1G	4.86
	H714G	1G	3
4P 2.5G	H355Z	2.5G	5.31
	H814G	2.5G	4.57
	GM404	2.5G	8.35

2.5G Speed – 2Pair Cable			
CPE WAN	CPE Model	Real Link	Link Time
100M	D firm	100M	3.63
4P-1G	M firm	100M	4.80
2P 500M	H614G	100M	14.90
2P 1G	H355A	1G	14.87
	H714G	1G	16.99
4P 2.5G	H355Z	1G	15.11
	H814G	1G	14.24
	GM404	1G	17.67

Table 5 shows the results of Korea's High Speed Internet Subscriber Ratio. Until early 2000, xDSL technology services were mainly provided to korea subscriber base for high-speed internet services, but since the government announced plans to advance the high-speed internet infrastructure, FTTH subscribers have grown[13].

TableⅤ. Korea's High Speed Internet Subscriber Ratio [13].

Article	LAN	FTTH	HFC	xDSL
Ratio	39.1%	34%	20.8%	6.1%

Korea ISP's can apply the 2.5GBase-T service to FTTH and LAN customers. Since 2018, Domestic A company have been applying heterogeneous compatibility to their LAN customers.

IV. CONCLUSION

This study proposes a system and related methods to achieve mutual compatibility among devices. To do this, the proposed system is designed to set up at least one optimized link connection automatically for different data transmission environments of both new and existing ONU/CPE devices that are installed to provide Internet service. In particular, a link speed option is allotted for each customer's service product, whether it is a standardized one or a non-standardized one, in order to enhance the service quality that is recognized by customers. As devices with the automatic setting function and existing network infrastructure are used, Internet services, including Giga Internet, are provided in a stable manner. In addition, high-quality Internet service is provided, regardless of the data transfer environment, to the satisfaction of customers.

While existing methods provide Internet services using automatic link setting only among standardized devices that are manufactured by the same company, this study proposes a method to automatically realize the link setting among both non-standardized and standardized heterogeneous devices. In the future, the amount of subscriber traffic will increase drastically with the increase in the use of high-speed data transfer services and smart devices. Accordingly, the technology will advance even to accommodate 10G service for subscriber CPE units, and future studies, therefore, must develop platform devices that can provide services that reflect the customers' device types and available service speed options.

Acknowledgment

This paper was prepared by the SK Broadband Consortium as part of the "2018 10Giga Internet commercialization Project," which is a joint project of the Ministry of Science and ICT and the National Information Society Agency (NIA).

References

[1] Wan, J., Tang, S., Shu, Z., Li, D., Wang, S., Imran, M., & Vasilakos, A.V. "Software-defined Industrial Internet of Things in the Context of Industry 4.0", IEEE Sensors Journal, Vol.16, no.20, pp.7373-7380, 2016

[2] Digital Times, "Internet Traffic to Be Tripled by 2021 "http://www.dt.co.kr/contents.html?article_no=2017071102109931037001," Jul.2017

[3] J.H. Park, G.Y. Kim, G.Y. Park, J.H. Kim, "The Direction of Next-generation Access Networks, A Collection of Essays", Conference on Information Communication Facility, Aug., 2007.

[4] Jun-ichi Kani, "Next-Generation PON-Part I: Technology Roadmap and General Requirements", IEEE Communication Magazine, Nov. 2009.

[5] T.W. Kim, S.I. Lim, "Telco's View on the NBASE-T Ethernet Technology for Giga Internet Service", Summer Academic Conference, Korea Information & Communications Society, 2016.

[6] J. H. Kim, S.J. Lee, S.G. Oh, "Design of UTP LAN Cable with Enhanced Alien Crosstalk Characteristic", KICS, Vol. 37A, no. 12, pp.1115-1121, Dec. 2012

[7] Tae-gyu Kang, Han-cheol Doh, Seung-su Lee, Yong-uk Nah, Sang-seop Song, "Auto-Negotiation Design for 1000Base-X Physical Measurement", In Proc. KICS Autumn Conf., pp.1877-1880. Nov. 1991.

[8] Yinan Wang, Haijun Liu, "Design and Realization of Gigabit Ethernet Interface Based on FPGA", 3rd International Conference on Computer Design and Applications, 2011

[9] NBASE-T Ethernet Technology, Basis for the IEEE 802.3bz Standard, 2016, NBASE-T. NBASE-T Alliance. Retrieved 2015-10-18. http://www.nbaset.org/technology/, Oct.2015

[10] Kramer, Glen, and Gerry Pesavento. "Ethernet passive optical Network (EPON): building a next-generation optical access network", IEEE Communications magazine, Vol. 40,no.2, pp. 66-73. 2002

[11] NBASE-T Physical Layer Specification version 2.3, 2016 NBASE-T Alliance, Inc. All rights reserved. 2016

[12] Effenberger,F., Cleary, D., Haran, O., Kramer, G., Li, R. D., Oron, M., & Pfeiffer, T. "An introduction to PON Technologies[Topics in Optical Communications]", IEEE Communications Magazine Vol.45,no.3, pp.S17-S25, 2007.

[13] S.U. Cho, Y.C. Jeong, M.S. Lee, H.O.Jeong, S.S.Yu, H.G. Hong, Y.J. Kwon, S.Y. Hong , "A Study on Analyzing Communications trends and Market Forecast, Korea Infromation Society Development Institute", pp.20~23,Dec.2016