A study on technologies that enable high-speed communication regardless of the interface standard between the host devices and peripheral devices

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Abstract. Recently, I/O interfaces for connecting a computer to peripheral devices have emerged to provide 10Giga services for communication companies. Therefore, Intel has developed Thunderbolt cables, which enable electrical signals and high-speed data transfer to facilitate 10Giga services. Thunderbolt is a type of input–output interface that is used to connect computers and peripherals. It is capable of high-speed input/output(I/O), incurs lower overheads than USB, and supports data, images, and voice simultaneously. As these are very recent standards, they have not been applied to many computers. Moreover, no device exists to use interfaces having a different protocols while differentiating between Thunderbolt and USB devices. Therefore, if both interfaces are mutually incompatible, the user must utilize Thunderbolt or USB devices separately. For this reason, a device that automatically identifies Thunderbolt or USB and automatically adapts to the user’s environment is required. In this study, Thunderbolt MAC and a MAC are alternately connected to each other via an electrical Multiplexer to auto detect link information and connect to Host. Then, based on the determined result, the Thunderbolt to PCIe bridge or the USB to PCIe bridge is electrically connected to the PCIe BUS to which the Multiplexer is connected.

1. Introduction
Recently, as a variety of services such as 5G, 8K UHD, and OTT have emerged, the IP and Internet traffic increases per person have surpassed the level of existing gigabit Internet service in the last decade. Consequently, subscriber traffic has increased rapidly Globally, the monthly IP traffic will increase from 16 GB per person in 2017 to 50 GB person in 2022, and the Internet traffic will increase from 13 GB per person in 2017 to 44 GB per person in 2022 [1]. Also, By 2020, forecasts suggest that there will be around 6.58 network connected devices per person around the globe. With a total world population of over 7.5 billion people, this means that there could be nearly 50 billion network connected devices by 2020[2]. As network connection devices have greatly increased to provide ultra-high definition, ultra-low delay and 8K video technology, increase interconnection bandwidth requirements between end devices and the interconnect technology is determined by the device model used by customers [3]. Therefore, devices to devices, 5Gigabit, 10Gigabit per second (Gbps) Internet connection technology is required to provide stable, large capacity, and high quality service such as hyper-realistic UHD media, virtual reality (VR), and augmented reality (AR) services and 802.11ax.

New interface standards have been continuously researched and developed to improve inter-device interconnection.
communication speed and performance. Therefore, Intel Corp. and Apple Inc. have jointly developed Thunderbolt, which is an ultra-high speed PC interface standard between devices, to facilitate high speed data transmission between PC and LAN card in order to utilize 10Gbps-class Internet [4]. The technologies of inter-device interface standards facilitate interconnection between independent devices having mutually different input and output technologies to ensure high speed communication speed. This paper suggested a novel technique that detects link information to connect to a host such as a computer by alternately-connecting the data signals of a USB connector to Thunderbolt MAC and USB MAC through an electrical multiplexer to facilitate high-speed communication between a computer and a peripheral regardless of interface standards.

Furthermore, interface enhancement between a computer’s CPU and LAN card is crucial for providing broadband Internet service. However, as computing has shifted to emphasize on becoming mobile-oriented, light, and small, there is insufficient space for I/O connector arrays for various applications [4].

In addition, as notebook PCs become thinner, the physical space to accommodate interface connectors is restricted. In order to maintain the current interface functions and secure expandability at the same time, more than one existing interface component must be integrated into one. Thunderbolt has been proposed to solve this problem [5]. Thunderbolt combines PCI Express (PCIe) and DisplayPort (DP) into two serial signals, and additionally provides DC power, all in one cable. Up to six peripherals may be supported by one connector through various Topologies [6-7]. Thunderbolt is an I/O interface cable that is used to connect a computer with peripherals. Because it facilitates high speed input/output, it has lower overheads than USB while supporting data, video, and voice simultaneously. Few computers support Thunderbolt because it is a latecomer, and the majority of computers still support USB. However, because the two interfaces of Thunderbolt and USB are incompatible with each other, the devices should be used separately when connecting a computer to external peripherals. Moreover, there is currently no device that distinguishes computer interfaces having mutually different protocols, such as Thunderbolt, USB, and power supply, in the device aspect. Therefore, because device interfaces are incompatible with each other, devices for Thunderbolt and devices for USB must be differentiated for the user. To solve the compatibility problem, a technology is required to automatically connect interfaces between devices according to the user environment.

This study designed a technique that detects link information to connect to a host such as a computer by alternately-connecting the data signals of a USB connector to Thunderbolt MAC and USB MAC through an electrical multiplexer to facilitate communication between the computer and a peripheral regardless of interface standards. Furthermore, a docking station device was developed to electrically connect a Thunderbolt-to-PCIe bridge or a USB-to-PCIe Bridge to PCIe BUS to a multiplexer based on the determined result. This study describes the patent application and device development conducted jointly with Dayou Plus Co., Ltd. for a study on the automatic compatibility of interfaces between devices. This paper is structured as follows. Section 2 describes the components and operating principle characteristics of 10Gbps-class Internet networks and multiplexers. Section 3 Research and Experiment, and lastly, Section 4 presents the conclusion.

2. Operating principle of compatibility between devices using thunderbolt

2.1. Interface between devices using thunderbolt

Recently, computing has become mobile-oriented and consequently, a considerable proportion of notebook computers to be released in future are expected to be in the ultrabook form. Thus, notebook computers will become thinner and have limited physical space for accommodating interface connectors [4]. To maintain the current interface functions while simultaneously possessing scalability, two or more existing interface components should be integrated into one. To address this issue, Intel Corp. and Apple Inc. jointly developed and proposed Thunderbolt, an ultra-high speed PC interface standard between devices [4]. Thunderbolt is an I/O interface cable used to connect a computer and peripherals, and it was developed by Intel. Because Thunderbolt facilitates high speed input/output, it
has lower overheads than USB and supports data, video, and voice simultaneously. However, because the standard was a latecomer, few computers currently support it.

Fig. 1 shows that communication is facilitated by connecting a Thunderbolt cable through a docking station between an optical modem and interface hardware of various hosts or computers. Because computers are becoming thinner, lighter, and smaller, there is almost no space available for an I/O connector array [3]. Thunderbolt cables are classified into two types: copper and optical. However, this study was conducted based on copper cables to supply electrical power as well between a host and end devices. Based on the USB standard, copper is used by limiting the cable length to 5 m for 480 Mb/s USB 2, 3 m for 5 Gb/s USB2, and 1 m for 10Gb/s USB 3.1 Gen2 [3]. Thunderbolt is a dual protocol I/O technology, developed for performance, simplicity, and flexibility, that can transmit data using a longer and more expensive cable by combining PCI Express and display port with a new serial data interface [8]. Peripheral component interconnect (PCI) is a high speed bus developed by Intel in the early 1990s to replace low speed bus technologies such as EISA, ISA, MCA, and VESA [9]. Thunderbolt is based on the Mini Display Port connector developed by Apple and is implemented in various customer devices such as laptops by using small connectors [8]. As the Thunderbolt3 cable has been released recently, USB3.1 Gen1/Gen2, DisplayPort1.2, and PCIe Gen3 tunneling are all included in a PC, thereby supporting high speed I/O protocols [3]. Fig. 1 shows a docking station that interconnects all Thunderbolt and USB type interfaces.

2.2. Operating method of Thunderbolt and docking station

In Fig. 2, the Thunderbolt cable, unlike a bus-based I/O architecture, provides the entire bandwidth of the link in both directions without sharing the bandwidth between ports or the upstream and downstream directions when communicating with a computer. A Thunderbolt connector can provide two full duplex channels. Each channel provides bidirectional high speed 10Gbps bandwidth. Physical speed provides down load 20Gbps x 2, Upload 20Gbps x 2. And Logical speed provide download 40Gbps, Upload 40Gbps. A computer’s Thunderbolt connector is connected to a Thunderbolt product or a DisplayPort device via a cable [6]. In Fig. 2, the Thunderbolt cable has a built-in dedicated transceiver IC in the connectors at both ends and compensates for time delays by amplifying signals to transmit high speed 10 Gbps signals. Furthermore, for internal high speed communication, lanes are composed with a dedicated upload pair and a download pair to allow upload and download transmissions to be performed independently and simultaneously [2]. Because Thunderbolt’s Interconnect technology can support 40 Gb/s throughput per connector interface, it is leading the adoption of interconnect technologies for various devices with respect to 8K videos and Internet speed [7]. Thunderbolt cable provides four times the data and twice the video bandwidth of any other cable, while also supplying power, 8 lanes of DisplayPort 1.2, supports two 4k displays(4094x2160 30bpp @60Hz)[10].
USB, as detailed in Table 1, is a typical interface standard used for connecting a host device, computer, and peripheral devices because it is economical and exhibits excellent performance. A main controller is present at the uppermost part, and two USB ports are provided through the root hub. Therefore, if there is an insufficient number of USB ports, more USB ports can be prepared by connecting a hub. As shown in Table 1, USB-C type connectors have been used since USB 3.1 Gen1. As shown in Table 1 and Fig. 2, Thunderbolt provides a 10Gb/s bidirectional transmission channel on two lanes, thereby facilitating much faster high speed data transmission than those of other standards [4]. A Thunderbolt connector can provide two full duplex channels. Furthermore, it uses a protocol that transmits data and video through only one cable by providing PCI Express for data and a display port for video data [1]. The maximum delay time is set to 8 ns to process video data smoothly [4]. Because Thunderbolt is a standard that came out late, the majority of host computers still support USB. Moreover, because the USB and Thunderbolt interfaces are incompatible with each other, a user must purchase a relevant device after checking whether USB and Thunderbolt are supported when connecting the peripheral device to a host device or computer, which is inconvenient. Therefore, to resolve this inconvenience and allow simultaneous use of both devices, this study has developed a docking station, as depicted in Fig. 3, to facilitate inter-communication regardless of whether an interface standard is conformed.

Table 2 Compares the USB3.1 and Thunderbolt™3 features. Thunderbolt™ 3 brings Thunderbolt to USB-C at speeds up to 40 Gbps, creating one compact port that does it all — delivering the fastest, most versatile connection to any dock, display, or data device. For the first time, one computer port connects to Thunderbolt devices, every display, and billions of USB devices. A single cable now provides four times the data and twice the video bandwidth of any other cable, while also supplying power. It’s unrivaled for new uses, such as 4K video, single-cable docks with charging, external graphics, and built-in 10GbE networking [5].

For the docking station represented by the red dotted lines in Fig. 3, a data-providing port was developed to facilitate 10Gb/s and 5 Gb/s transfer simultaneously. Furthermore, it was designed to detect link information and connect to a host such as a computer by alternately connecting the data signals of a
USB connector to both Thunderbolt MAC and USB MAC through an electrical multiplexer. According to the final result determined, the docking station device was developed to electrically connect the Thunderbolt-to-PCIe bridge or USB-to-PCIe bridge with the PCIe BUS connected to the multiplexer.

Table 1. Device interface standards [4]

| Standard        | Thunderbolt (USB 3.1 Gen2) | USB2.0        | USB3.0(Gen1) |
|-----------------|---------------------------|--------------|-------------|
| Transmission    | Bidirectional 10Gb/s      | Bidirectional 480 Mb/s | Bidirectional 5 Gb/s |
| speed           | 2 lanes                   | 1 lanes      | 1 lanes     |
| Cable length    | Max. 3 m(electrical)      | Max 5 m      | Max 3 m     |
| Max. 30 m(optical) | Data transmission       | Tree connection | Tree connection |
| Feature         | Daisy-chained             | Power 2.5 W  | Power 4.5 W |
| Power 10 W      |                           |              |             |
| Established     | 2011                      | 2000         | 2008        |

Table 2. Analysis of Thunderbolt™3 and USB3.1 [5]

| Capability              | USB 3.1 | Thunderbolt™ 3 |
|-------------------------|---------|----------------|
| Small and reversible    | ●       | ●              |
| Connects to USB Devices | ●       | ●              |
| Speed                   | Up to 10Gb/s | Up to 40Gb/s |
| Fastest data, video, and power | ○         | ●              |
| Two 4K displays         | ○       | ●              |
| External graphics       | ○       | ●              |
| Single-cable docks with two 4k displays | ○       | ●              |

Each channel provides bidirectional 10Gbps bandwidth. A Thunderbolt connector on a computer is capable of connecting to a Thunderbolt product or a DisplayPort device through a cable [11].

3. Research and experiment

Fig. 4 depicts a 10Gbps network by classifying an apartment building and a detached house. XGS-PON installed in the Internet network is a device that provides 10Gbps speed upstream/downstream to a customer’s Home ONT device through an optical cable and a splitter. The XGS-PON technology is a technical standard that was presented by the Full Service Access Network (FSAN) group in 2010 [12]. The tree architecture is very fiber efficient as only a single feeder fiber is used to connect a central office to the local service area, where a passive optical splitter provides onward connectivity to each subscriber [13]. In a home network, broadband Internet service is provided through an integrated docking station on a PC that provides 10Gbps speed by detecting Thunderbolt, power delivery, and USB3.x interfaces and connecting to a USB-C connector via an electrical multiplexer. Internet, IPTV, and WiFi services are provided to B2C customers of wired communication by targeting apartment buildings and detached houses; according to the needs of customers, speeds of 1, 2.5, 5, and 10Gbps are provided. To receive such a variety of speeds, an interface between devices should be used by connecting to different devices. For example, when a customer wants high-speed 10Gbps service, the network should be designed with a high-speed serial-bus and memory interface to overcome the problems of various interfaces and standards such as USB3.1, Thunderbolt3, DisplayPort, HDMI, and PCIe on a PC [14]. Furthermore, to ensure high-speed communication, the I/O interface technology between devices should facilitate inter-device communication by connecting different devices with each other.
Even if the cable connectors in a USB-C interface connected to a computer in a home network are identical, the interface standards may be different. In such a situation, a docking station is required to use high-speed 10Gb/s or 5Gb/s Internet by freely connecting the computer and peripheral devices without differentiating Thunderbolt, USB, and power delivery devices. The docking station connects a host device such as a computer to peripheral devices, and when a new peripheral USB device is connected to a connection port of the device, it determines whether the interface standard of the connected computer has been identified. If the computer’s interface standard has not been confirmed, a certain signal is processed as signals of USB and Thunderbolt standards and transmitted alternately to the computer.

![Diagram of the docking station](image)

**Figure 5.** Diagram of the docking station

Fig. 5 depicts the solution that facilitated the simultaneous use of Thunderbolt, USB, and power delivery, as tested in this study. As shown in the docking station diagram in Fig. 5, the connector signal Multiplexer enables a connection between a USB connector’s connection port and a USB PCIe bridge; subsequently, it is controlled to make a connection between a USB connector’s connection port and a Thunderbolt MAC PCIe bridge. Furthermore, after a certain signal generated in the docking station is processed as a USB standard signal at the USB PCIe bridge, it is transmitted to Thunderbolt;
then, after processing the certain signal as a Thunderbolt standard signal at the Thunderbolt Mac PCIe bridge, it is transmitted to Thunderbolt. The docking station allows the connector signal Multiplexer to establish a connection between the USB connector’s connection port and the USB PCIe bridge; afterwards, it is controlled to make a connection between the USB connector’s connection port and the Thunderbolt Mac PCIe bridge. Furthermore, it allows the PCIe bus Multiplexer to connect the PCIe bus to the USB PCIe bridge while the connector signal Multiplexer makes a connection between the USB connector’s connection port and the USB PCIe bridge. In addition, while the connector signal Multiplexer connects the USB connector’s connection port to the Thunderbolt Mac PCIe bridge, the connection between the PCIe bus and the processing part is controlled such that, after processing a certain signal, i.e., a signal of a USB device at the USB PCIe bridge, it is sent to the computer; then, after converting the signal into a Thunderbolt standard signal at the Thunderbolt Mac PCIe bridge, it is sent to the computer. Furthermore, according to the determined result, the docking station device was developed to electrically connect the Thunderbolt-to-PCIe bridge or USB-to-PCIe bridge to the PCIe bus, which is connected to the multiplexer. It was developed to facilitate automatic compatibility of interfaces between devices.

After developing the diagram in Fig. 5, the hardware and software of both the host computer and Thunderbolt should be prepared prior to testing to facilitate 10Gbps-class high-speed communication between the computer and peripheral devices. First, the notebook computer should be capable of using Thunderbolt3 because it must use a mainboard with an 8th generation or higher Intel CPU and a chipset supporting 40 PCIe lanes at most. In other words, in terms of satisfying the PCIe version and Thunderbolt lane requirements in the experiment, PCIe x1 implies that the bandwidth per lane based on the PCIe ver. 1.0 is 250 MiB/s (half-duplex) because, in the case of x16 sockets, which are typically used for graphic cards, 16 PCIe x1 lanes are allocated with a bandwidth of 250*16 = 4 GiB/s (half-duplex). The latest version of the PCIe standard released is ver. 3.0, and although a device using a higher version of PCIe can be mounted on a slot of a lower version, the bandwidth is restrained by the lower one among the two. Therefore, depending on the mainboard, there may be 16 lanes slot in shapes while filling only four or eight lines for the actual contact points. An opposing case also exists; a slot can be inserted regardless of device-side lane because the end parts of lane slots such as 1x, 4x, and 8x are opened. In both cases, a slot and a device operate with an electrically connected lane alone. The host computer is recommended to utilize a built-in graphic function on the CPU if possible, and although main boards may all look similar, there may be a limitation in the number of PCIe lanes. Particularly, in the case of AMD, the Ryzen2 Mainboard Chipset supports only 24 PCIe lanes at most. Furthermore, it cannot use a 10Gbps LAN card because the lanes consist of x16 for graphic cards, x4 for SSD, and x4 for CPU. For a case of minimal use for AMD, the built-in graphic function on the CPU is used, and 10Gbps LAN card is mounted on the x16 slot. Sometimes, a main board having two x16 slots should be used, and in this case also, there is usually a constraint that the primary slot is for x16 and the second slot is for x4. Furthermore, if there is no forced allocation function of the x8/x8 type in the ROM BIOS, the graphic card must be inserted into the second x4 slot and the 10Gbps LAN card in the primary x16 slot even if the graphic card’s performance drops. If the graphic card is inserted into the primary x16 slot, the graphic card automatically gains control over the x16, thereby creating collisions with the second slot. In terms of CPU performance requirements, two cores or more is sufficient, but if running heavy programs such as a Web browser, it will contribute to speed fluctuation. Although PCIe 2.0 can also be used, it is based only on a theoretical maximum speed and its performance deteriorates. Therefore, it is advised to use a main board with PCIe version 3.0 if possible. In the case of Windows, background programs such as firewalls and Windows Defender should be stopped. When testing the 10Gbps full speed, the CPU cannot read the Rx buffer value of the 10Gbps LAN card and packet buffer losses occur while the above mentioned functions are being operated. Therefore, in the case of a slow CPU, the 10Gbps card buffer should be increased, the interrupt should be minimized, and the FlowControl function should be avoided. Based on these test environment conditions, a block diagram of the docking station was designed, as shown in Fig. 5.
Start

Host device Connection

Peripheral connection

Is the host devices interface specification verified?

Yes

Identifies the interface specification of the host device according to the Link Information

No

Process and transmit a specific link information as a signal of the first and second interface specification

Identifies the interface specification of the host device according to the Link Information

A Communication path is formed between the first and second multiplexing control, the host connection unit and the device connection unit

When disconnecting peripheral device, initialize communication path

Fig. 6. Experimental procedure for docking station

Fig. 6 shows a flowchart depicting the experimental procedure that processes a signal at the Thunderbolt MAC and USB MAC by identifying the interface standards when a host computer and a peripheral device are connected with a variety of communication devices. In other words, for a variety of communication devices, a communication path is formed at a port between the host device’s connector and the peripheral device’s connector alternately through the peripheral device’s connecting PCIe bus, which connects the USB connector of the connector signal Multiplexer and the Thunderbolt signals. In the first step, the interface standard of the host device is checked and a signal is processed as the signals of Thunderbolt MAC and USB MAC interface standards or transmitted alternately. In the second step, the time information is included in the link information so that the interface standard of the host device can be identified during the process of connecting the host computer with the MAC layer processing functions of Thunderbolt and USB, respectively. In the third step, when the interface standards of various communication devices are identified, the connector signal Multiplexer and the PCIe bus Multiplexer are controlled to establish communication paths between the host device and the peripheral connectors.

4. Conclusion

This study performed research and development for the automatic compatibility of computer and peripheral devices according to new interface standards while improving the speed and performance of wired communication. When Thunderbolt capable of high-speed I/O is used as an interface, the overheads are lesser than those of USB, and data, video, and voice are supported simultaneously. However, there are few host devices supporting Thunderbolt, and presently, although most hardware supports USB connections, interconnection between USB and Thunderbolt is incompatible with each other. Therefore, when connecting peripheral devices to a host computer, the user should check the computer and the peripheral devices and utilize them by distinguishing suitable Thunderbolt- and USB-supporting devices. This study facilitated intercommunication among Thunderbolt, USB, and power delivery devices regardless of interface standards between the computer and peripheral devices. To accomplish this, the link information was detected and a connection was made with the host device.
computer by alternately connecting data signals of a USB connector with the Thunderbolt MAC and the USB MAC through an electrical multiplexer. Furthermore, a docking station device was developed to implement an electrical connection of Thunderbolt-to-PCIe bridge or USB-to-PCIe bridge and PCIe BUS connected to the multiplexer based on the determined result. Consequently, the users no longer faced the inconvenience of identifying the interface standards of a computer individually and distinguishing Thunderbolt, USB, and power delivery devices during use. Moreover, users can expect an increasing degree of freedom of interface between devices and improved convenience. Therefore, this docking station overcomes the limitations of conventional technology and has sufficient potential for the commercial release or sale of devices using the relevant technologies. Moreover, it can be utilized efficiently in the high-speed communication industry.

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