# Evolution of Video Communication and Sumitomo Electric's Mission

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Video distribution traffic accounts for 65-70% of the downstream access network traffic, which has continued to grow in recent years. Advances in video image quality and video compression technologies, coupled with standardization efforts, have led to a significant increase in the maximum required bandwidth per broadcasting channel. Specifically, over the last two decades, the maximum content bitrate has multiplied by approximately 40 times (pre-compression), and 20 times (post-compression) for IPTV, while domestic radio frequency broadcasting has shown the pace of 5 times. At the same time, the future growth of the market is anticipated to be driven not only by the transition to 8K video but also by the integration of Extended Reality (XR) video services that combine 360° 3D video, AI, and digital twin technologies. Taking this opportunity, this paper reviews the trends in video communication technology and the initiatives of Sumitomo Electric Industries, Ltd. The paper also discusses various key indexes required for all-optical and wireless networks connecting cloud computing to homes and workplaces, with a particular focus on what is called the Motion-to-Photon latency, which is essential for realizing immersive and interactive 3D and XR video distribution services, and considers its impact on other key indexes.

Keywords: video distribution, 3D, XR, all photonic network, motion-to-photon

## 1. Introduction

Today, next-generation immersive and interactive XR (cross-reality or extended-reality)*1 video services, which are made from free-viewpoint 360° 3D video in combination with AI, digital twin, and avatar technologies are being explored, and going to innovate and transform the entertainment and social activities. IOWN (Innovative Optical and Wireless Network) Global Forum and 3GPP (Third Generation Partnership Project) have started discussing use cases, functional architectures, and requirements for these services. To enable these services, the communication networks and applications that connect cloud computing in data centers to the real world must have 1) high speed and high capacity, 2) low latency, 3) high power efficiency, and 4) high resilience and security at levels that go one step beyond conventional technologies. This paper reviews the trends in video communication, which has accounted for the majority of broadband internet/IP traffic, and Sumitomo Electric Industries, Ltd.'s efforts in this area, with the hope of helping the industry make a leap forward in the era of the major transition.

## 2. Overview of Video Distribution Traffic

In 2022, the market size of video distribution services was US$10.67 billion globally (18% increase year on year) and ¥530.5 (approximately US$3.5) billion in Japan (15% increase year on year).(1) It was reported that, in the first half of 2022, internet video traffic, such as YouTube and Netflix, accounted for 65.9% of the global internet traffic, and it increased by approximately 23% per year from 53.7% for the same term in the last year.(2) However, the above statistics for internet video traffic do not include the IP video distribution traffic managed by IPTV and CATV operators. In the case of Comcast, the world's largest CATV operator, for example, announced that all the video distribution traffic (including both the internet video and managed IP video) occupied 71% of the downstream peak traffic in 2021.(3) In this way, the video distribution communication traffic dominates the majority of network traffic.

The required network bandwidth between the cloud/station and the client for the distribution of video information is defined by Eq. (1), when video rendering is performed in the cloud or station.

$$\text{bit rate (bps)} = \frac{\text{resolution (e.g.: 4Kx2K)} \times \text{frame rate (fps)} \times \text{color depth (8,10,12 bit)} \times \text{primary colors(3)}}{\text{chroma sampling in video acquisition (RGB 4:4:4=1, YCbCr 4:2:2=1.5, YCbCr 4:2:0=2, Dual Green=3)}} \times \text{\# of stereoscopic viewing angles} \times \text{video compression ratio} \quad \cdots\cdots (1)$$

Based on the improvement of video quality (in resolution, frame rate, color depth, and so on), the video transmission bit rate before compression has been increased by the rate of approximately 40 times in 20 years. However, video compression technology has also continued to evolve, and the compression rate of de jure standardized video compression technology in Table 1 has improved by around 5 times per 20 years. As a result, the maximum bit rate for video streaming after compression in de jure standard is increased around 20 times per 20 years as shown in Fig. 1. The figure also indicates that, in Japan, the video bit rate for distribution after compression for IPTV shows almost the same aggressive rate of increase as standardization, while RF digital broadcasting increased by around 5 times in 20 years.

As estimated from Fig. 1, the maximum video streaming bit rate for IPTV in Japan has doubled in about 4.5 years, and the increase in IPTV streaming bit rate after Y years can be estimated by Eq. (2).

$$\text{GRB (Growth Rate of Bandwidth)} \fallingdotseq 2^{(Y/4.5)} \quad \cdots\cdots \text{(2)}$$

Now, we are exploring new technologies and standardization activities for next-generation 3D and XR video distribution. The following chapter looks back at the history of video information distribution technology in Sumitomo Electric and the market transition. Chapter 4 considers technological trends for 3D and XR video distribution.

Table 1. Evolution of video compression technology in standard

| Standard | ITU-T | H.262 | H.264 | H.265 | H.266 |
|---|---|---|---|---|---|
| | ISO/IEC | MPEG-2 | MPEG-4 AVC | MPEG-5 HEVC | MPEG-I†2 VVC |
| Standardization completion year | | 1995 | 2004 | 2013 | 2020 |
| Major use cases | | Digital Broadcast, DVD | Broadcast for mobile, IPTV, BD | 4K/8K | 360°, 3D Immersive, HDR |
| Maximum resolution | | 2K | 4K | 8K | 16K/3D |
| Maximum frame rate | | 30 fps | 60 fps | 120 fps | 120 fps |
| Applicable color depth | | 8 bit | 8 to 12 bit | 8 to 16 bit | 10 to 16 bit |
| Applicable chroma sampling format in video acquisition [data reduction] | | 4:2:2,4:2:0 [1/1.5, 1/2] | 4:4:4,4:2:2,4:2:0 (,Dual Green) [1/1, 1/1.5, 1/2 (,1/3)] | | |
| Typical video compression ratio (e.g.) | | 55:1 | 110:1 | 220:1 | 440:1 |
| An example of streaming bit rate compressed by each standardized technology †1 (bps) | | | | | |
| Video format example (resolution, frame rate, color depth, chroma) | Bit rate w/o compression | Approximate bit rate w/ compression | | | |
| HD 30 fps 8 bit 4:2:0 | 0.7 G | 14 M | 7 M | 3 M | |
| 4K 60 fps 8 bit 4:2:0 | 6.0 G | | 55 M | 27 M | 14 M |
| 8K 60 fps 10 bit 4:2:0 | 31.9 G | | | 145 M | 72 M |
| 16K 120 fps 10 bit 4:2:0 | 318.5 G | | | | 724 M |

†1: Actual bit rates for commercial services are subject to be different from the value of this table in case different video format and/or different de fact standard technology are applied

†2: Immersive

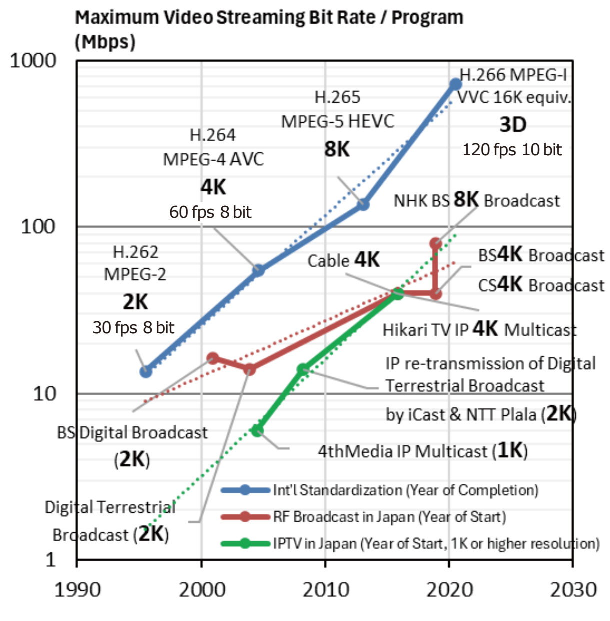



Fig. 1. Growth trend of maximum video transmission bit rate after video compression

## 3. Looking Back on Video Streaming and Broadband Technology in Sumitomo Electric

### 3-1 Fountain of challenge: Life support video information system "Hi-OVIS"

Sumitomo Electric's approach to video information distribution technology dates back to 1978 when the Company launched the world's first two-way optical CATV system Hi-OVIS.(4) Supported by the Ministry of International Trade and Industry, the Hikari Center, about 150 ordinary households in Ikoma City, Nara Prefecture, and six public facilities were connected by optical fiber, making it the world's first attempt to perform two-way video communication. Experiments were carried out to pioneer current data broadcasting services such as weather forecast, local government information, and traffic information. Dedicated terminals were installed in homes and facilities, and request signals from the terminals were processed by the computer at the center to activate video sources and control video switches to provide service to each home. Sumitomo Electric has been working on the development of core products and technologies such as optical fibers, optical data links (photoelectric conversion modules), transmitters/receivers, and video switching equipment. It was introduced as an example of the future society and visited by Emperor Showa in 1984, drawing interest. It had a great influence on subsequent businesses and the challenging attitude of young engineers. In 1999, the CATV system business led to Broad Net Mux Corporation (BNMUX), which was established as a joint venture of Sumitomo Electric and Toshiba Corporation.

### 3-2 Spread of the Internet and pioneer of video IP distribution

The Internet was developed based on the "ARPANET," a network of computers connected in a mesh architecture, and began to be developed in 1969 with funding from the US Department of Defense Advanced Research Projects Agency (now DARPA). In 1993, the European Organization for Nuclear Research (CERN: Conseil européen pour la recherche nucléaire) released the World Wide Web (WWW) for commercial use. In the same year, the National Center for Supercomputer Applications (NCSA) Laboratory at the University of Illinois developed the revolutionary Web browser Mosaic, which later became Netscape and then Internet Explorer. In Japan, the first Internet service was launched in 1993, and on January 17, 1995, at the dawn of the spread of Internet services, the Great Hanshin-Awaji Earthquake occurred. Telecommunications and broadcasting infrastructure were damaged by the earthquake, making it difficult for video information from the disaster area to reach national and local governments, NPOs, the media, and affected people.

On the other hand, many local universities, companies, research institutes, and individuals sent images of the disaster areas, safety information, and academic information on the earthquake to the world through the Internet. The total number of accesses to the "Earthquake Information" menu for personal computer communication exceeded one million within 29 hours of its opening on the day of the earthquake, demonstrating the resilience and convenience of the Internet.(5)

Sumitomo Electric aimed to realize a real-time video distribution system over the Internet infrastructure. In 1997, two years after the Great Hanshin-Awaji Earthquake, the Company developed an "MPEG2 real-time video server system Suminet-5900," which compressed video streams from investigation cameras along the road and river to 2 to 8 Mbps (studio quality at the time), transmit the transport stream through virtual LAN (local area netwotk) via optical backbone LAN "Suminet-3700," using asynchronous transfer mode (ATM) switching technology between camera sites and offices, and via 100M Ethernet within offices. We provided servers and applications for offices and citizens to select, remote control, record, play-back, and monitor the video from the Internet Explorer on Windows-95 PC in the office and provided the video streaming to the citizens via Internet across the firewall, in addition to the conventional dedicated monitoring screens in the facility management offices. In 1998, it was supplied to the Ministry of Land, Infrastructure, Transport and Tourism's various offices and river and road monitoring systems, including the road monitoring systems during the Nagano Winter Olympics and the river monitoring system of the Yodo and Tsurumi rivers (Fig. 2).

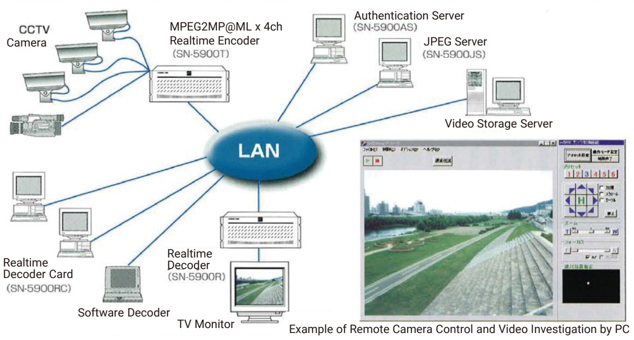



Fig. 2. MPEG2 real-time video server system for national highway and river video monitoring after the Great Hanshin-Awaji Earthquake Disaster (SEI Leaflet, 1998.9)

The Company also participated in a national project experiment to interconnect nine CATV stations in Hyogo Prefecture after the earthquake. Through these efforts, Sumitomo Electric has built up its experience in high-efficiency and high-quality video compression and Internet-friendly IP video distribution.

### 3-3 Market-in to the broadband access network and launch of first-generation IP-STB

In order to apply ADSL (asymmetric DSL) technology, which was standardized in the United States in 1995, to the public access networks in Japan, Sumitomo Electric developed the Dual Bitmap technology that synchronizes the ADSL transmission capacity with the operation cycle of Japan's existing communication system (ISDN). The Company added this technology to the ITU-T (International Telecommunication Union Telecommunication Standardization Sector) as a supplementary regulation for Japan in the Annex, jointly with other companies in the industry. As a result, the ADSL international standard was established in 1999, and Sumitomo Electric entered the broadband subscriber network market.[6] In terms of ADSL communication speeds and fees, fierce service competition has emerged in Japan, and broadband has spread ahead of the rest of the world.

Since 2000, in addition to the research and development of very high speed DSL (VDSL) for apartments and GE-PON, a favorable architecture for FTTH, as successor products, the Company has also devoted to the speed competition of ADSL (from 2 Mbps, 8 Mbps, 12 Mbps to 24 Mbps) and the density competition of the station equipment. In 2002, Sumitomo Electric Networks Co., Ltd. was established as a subsidiary to develop access broadband equipment (EPON, xDSL, STB) business in the telecommunications market. The shipments of VDSL began in 2002, and 70 to 100 Mbps products were released in the following year. In GE-PON, the Sumitomo Electric Group has overcome the burstiness problem of upstream signals from multiple subscribers with different conditions using (i) media-sharing control technology cultivated in LAN, (ii) knowledge accumulated as an optical component manufacturer, and (iii) the development of original analog IC. In 2004, the IEEE (Institute of Electrical and Electronics Engineers) standardized 1 Gbps GE-PON, and Sumitomo Electric started the delivery of station equipment and home premises equipment. Full-scale shipments began in 2005.

In parallel with these developments, video content on the Internet became increasingly high-definition, lengthy, advanced in compression technology, and borderless worldwide. Around this time, in Japan, digital high-definition broadcasting began at broadcast stations in Tokyo, Osaka, and Nagoya in 2003, and by 2006 it had spread to all prefectural capitals. In the world, many attractive video contents have started to be delivered over the Internet. The video quality demanded by the public audiences has become increasingly high in spite of the limited quality of service (QoS) of the broadband IP network, which shares the bandwidth on a "best effort" basis. However, TCP/IP, the basis of Internet communications, maintains QoS by retransmitting lost packets. During prime time, this mechanism increased bandwidth even more, resulting in more packet drops, which caused video freezes and glitches. In addition, TCP communication controls to keep the product of "round trip time (RTT)" and "communication throughput" (i.e., bit rate) to be constant. A problem arose in the content download, especially from the far end site, lost packet caused additional packet re-transmission, which further increased the RTT and significantly reduced the effective throughput of the network. At that time, the mechanism of "priority control" and "bandwidth guarantee" that allocated the priority of IP packet discard and reception buffer size according to the service class were not yet popular, it was essential and urgent to recover the lost packets by the method other than resending.

In order to solve this problem, the Company has invested in Digital Fountain Inc., which was a start-up company established in 1998 by Professor Michael Luby of the Institute for Science Research (ICSI), who was well known for leading the design and analysis of Tornado code and LT code, the world's first random LDPC error correction (FEC) codes, and are also known for structural analysis of Feistel cipher, together with Cisco Systems Inc. and Sony Corporation. We were mentored extensively by this company until it was acquired by Qualcomm, Inc. in 2009.

In 2002, in a national project of Telecommunications Advancement Organization (TAO), which is a predecessor of National Institute of Information and Communications Technology (NICT), an authorized corporation under the jurisdiction of the Ministry of Internal Affairs and Communications, Sumitomo Electric developed IP-STB, which equipped with the world's strongest FEC in those days named Raptor code that farther improved and evolved LT code to solve the above-mentioned issue. From 2003 to 2004, jointly with NTT-BB (NTT Resonant Inc's predecessor) and NEC Corporation, Sumitomo Electric successfully proved the effectiveness of FEC in increasing the audience rate in the world's first IP VOD (Video on Demand) field trial service with application layer FEC in the Tokyo Metropolitan Area (Fig. 3).[(7)]

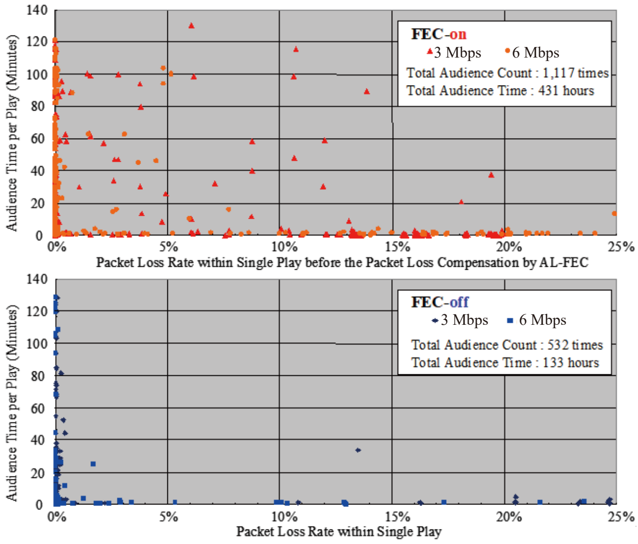
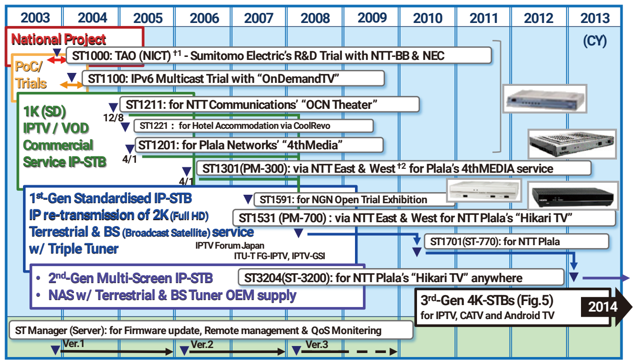



Fig. 3. Increase in audience opportunity by adopting the end-to-end AL-FEC scheme to improve the QoS in a field trial in Tokyo Metropolitan Area in 2003[(7)]

Immediately after the above field trial, the Company also experienced the IPv6 multicast video distribution trial for the "FTV" service of "On Demand TV" (JV of NIPPON TELEGRAPH AND TELEPHONE WEST CORPORATION (NTT-West), ITOCHU Corporation, and SKY Perfect JSAT Corporation) in early 2004. After these trials, Sumitomo Electric started the mass production supply of its IP-STBs to NTT Communications Corporation's "OCN Theater" service in 2004, Plala Networks Inc.'s "4thMEDIA" service in 2005, and NIPPON TELEGRAPH AND TELEPHONE EAST CORPORATION (NTT-East) & NTT-West in 2006.

In 2007, we participated in Nippon Telegraph and Telephone Corporation (NTT)'s NGN trial, developed the world's first IP-STB that supported the standardized IP-retransmission of full high-definition digital terrestrial broadcasting service, and worked to support customers in obtaining IP-retransmission permission for the service. There were many technological challenges, however, the Company devoted its efforts and a huge amount of testing resources, including abnormal system testing, to the development of two critical features. One was to make the latency between the RF broadcast service and the IP-retransmission service no more than 2.5 seconds while keeping the video, audio, and data quality of the service, to keep the "Contents' Identity." Another one was to implement DRM (Digital Rights Management), which was newly applied for the protection of full high-definition content distribution.

In the spring of 2008, massive shipments of the first-generation standardized IP-STB to NTT-East and NTT-West, which provided FTTH services, began for the "Hikari TV" service of NTT Plala, which was a unified service from the previous three IPTV services of the NTT Group. By March 2010, approximately one million units had been supplied to the NTT Group. The milestone is shown in Fig. 4.




†1: TAO is a predecessor of NICT (National Institute of Information and Communications Technology, Japan)
†2: NTT East & West: NIPPON TELEGRAPH AND TELEPHONE EAST CORP. & NIPPON TELEGRAPH AND TELEPHONE WEST CORP. For other official notation of the company and service name, please refer to the text and the trademark column on the last page.

Fig. 4. Launch of IPTV STB market

In IPTV standardization, in addition to the support to IPTV FORUM JAPAN, since 2006 Sumitomo Electric has contributed to ITU-T FG IPTV (Focus Group on IPTV) and IPTV-GSI (Global Standards Initiative), proposing draft documents such as on H.701 (Error Recovery) and H.721 (Terminal Device), and the discussions in the meetings. From 2010 to 2011, we also contributed to the interoperability tests at the ITU IPTV Interop Events in Geneva, Singapore, Pune, and Rio de Janeiro.[(8)]

### 3-4 Second-generation multi-screen IP-STB and digital tuner-equipped NAS products

In the second-generation IP-STB from 2010 to 2014, Sumitomo Electric realized the "Multi Screen" function by supporting DLNA (Digital Living Network Alliance) server function into the IP-STB. With the combination of the 2-ch simultaneous recording and playback function realized by triple IP tuner and external HDD management functions in the first-generation products, the second-generation products enabled the users of previously authorized and registered smartphones, tablets, PCs, and other IP-STBs to view the recorded IPTV contents in the home, live IPTV and VOD programs from other rooms and anywhere via IP-STB. In addition, in the second-generation, the Company has developed various types of advanced functions that are required for the “core information appliance server” in the living room.

Also, in this period, while making use of the CDN (Content Delivery Network) technology cultivated in the IP-STB, abolishing the direct video output function to the TV monitor from the STB, the Company created a NAS (Network Attached Server) product, which has a built-in HDD and RF tuner for terrestrial and broadcast satellite digital TV, developed for the Company’s partner. About 500K units of the first lot were supplied on an OEM basis.

In this period, Sumitomo Electric also contributed to the promotion of ITU-T standard-based IP-STB to Brazil, which had adopted the Japanese terrestrial digital broadcasting system (ISDB-T) and was preparing for the World Cup (2013) and Rio de Janeiro Olympics (2016). After the market research conducted from 2009 to 2011, the Company proposed an IP/RF-Hybrid-STB for PoC, which also implemented the local middleware “Ginga,” which was developed by Professor Luiz Fernando from PUC-Rio (Pontifícia Universidade Católica do Rio de Janeiro). After several evaluation tests made by the Portugal Telecom in Lisbon, the Company received a pre-order letter from Oi (Telemar Norte Leste S.A.), a major local telecommunications carrier in Rio de Janeiro.

Through these three projects, the Company acquired stable and lightweight graphical user interface technology for home appliances, the common platform development technology to efficiently proceed with multiple projects, the RF tuner and CAS technology, and world-class cost competitiveness, which were utilized in the development of its third-generation 4K IP Hybrid-STB and entry into the CATV market, as shown in the next section.

### 3-5 Third-generation 4K IP/RF/Android STBs, 10G-EPON, and 4K IP re-transmission servers

In August 2013, five years before the start of BS4K broadcasting in Japan (December 2018), Sumitomo Electric established the Ultra High-Definition Video Technology Group in its R&D Unit. The Company developed a reference model of 4K IP (Hybrid) -STB, which supported H.265/HEVC coding in addition to the conventional H.264/AVC video coding, and started making proposals to major telecommunications carriers and CATV multiple system operator (MSO)s in Japan and the United States.

In October 2014, for the world’s first commercial service of 4K 60 frames per second IPTV and VOD on Hikari TV launched by NTT Plala Inc., the Company started the delivery of 4K IP-STB “ST-4100” for early adaptors, which was the world’s first IP-STB compatible with the security requirements for the 4K premium contents of major movie content holders in the US.[9] The successor model for majority users “ST-3400” was released in 2016 and won the top sales of 4K IP-STBs in Japan.

In 2016, from Google LLC, Sumitomo Electric received Japan’s first 4K-STB certification for Android TV, which enables viewing the Over the Top (OTT) services such as YouTube and Netflix, which were expected the rapid growth of audience on the Internet, and started providing the IP-STB to KDDI Corporation’s “au Hikari TV” in June.[10] These OTT services are now widely spread in the world, by using the MPEG-DASH (Dynamic Adaptive Streaming over HTTP) protocol, which was standardized by ISO/IEC in April 2012. In MPEG-DASH, the video server provides the content with a set of streams with different bitrates (for different resolutions and/or different compression ratios) and the client dynamically changes the received stream step by step adaptively depending on the quality of the network so that the content can be played back in the highest possible quality with the minimum interruption according to the available bandwidth, packet loss and latency of the network.

In July 2017, through KDDI Corporation, Sumitomo Electric started offering a hybrid 4K compatible STB “Cable Plus STB,” which was able to be operated by voice recognition, and was compatible with CATV, IPTV, and Android TV services, to CATV operators in Japan. In December 2018, the Company also started offering the successor “Cable Plus STB-2,” which supported BS4K RF broadcasting.[11]

In September 2019, the Company released a 4K IP-STB “StreamCruiser SmartTV 4500 (ST-4500)” for NTT Plala, which supported the first BS4K IP-retransmission in Japan and Android TV in addition to the previous linear TV services of “Hikari TV” (terrestrial digital, BS digital, and multi-channel broadcasting).[12]

In December 2019, to KDDI Corporation, the Company started offering an IP-Hybrid 4K STB “J:COM LINK XA401” equipped with a DOCSIS 3.0 compliant cable modem and compatible with Android TV applications for J:COM, the world’s fourth largest CATV operator.[13]

In February 2020, to NTT DOCOMO INC., the Company started offering “Docomo TV terminal 02,” which was compatible with BS 4K, 4K HDR, Dolby Vision, Android TV, and Hikari TV.[14]

As a result of these efforts shown in Table 2, the Company’s cumulative domestic shipments of 4K STBs, which were capable of viewing 4K VOD exceeded one million units by December 2020, and that were capable of viewing both BS4K broadcasting and Android TV also exceeded one million units by May 2021, respectively, to contribute to the distribution of 4K content and the expansion of the domestic IPTV/CATV market.[15] In addition, as of August 2022, cumulative shipments to domestic customers exceeded five million units.

Table 2. Example of 4K-STBs which compliant with both 4K-IP/RF broadcasting and 4K-Android TV (as of CY2020)

| Release | Oct 2014 | Jun 2016 | Dec 2018 | Sep 2019 | Dec 2019 | Feb 2020 |
|---|---|---|---|---|---|---|
| Type | IP | IP | IP/RF-Hybrid | IP | IP/RF-Hybrid | IP |
| Customer | NTTPlala’s Hikari TV | KDDIs au Hikari TV | CATV operators via KDDI | NTTPlala’s Hikari TV | J:COM via KDDI | NTT DoCoMo |
| Photo |  | | | | | |
| Compliant 4K Services | 4K Multi-channel Broadcast/Multicast, 4K Video on Demand | | | | | |
| | | 4K Android TV | | | | |
| | | | BS (Broadcast Satellite) 4KBroadcast/Multicast | | | |
| Ref.s | (9) | (10) | (11) | (12) | (13) | (14) |

The above business growth has been made possible by the combination of standardization and the Company’s in-house common middleware platform “stbcore,” which minimized the term to go to market and high reliability.[16]

For the continuous scale of 4K services described the above, the migration of FTTH access systems, from 1 Gbps GE-PON (which began full-scale shipments in 2005 and cumulative shipments reached approximately 32 million lines as of October 2021) to 10 Gbps 10G-EPON was indispensable. Also for the continuous investment for 10G migration, attractive 4K services were important.

In 2014, Sumitomo Electric merged its two subsidiaries, Sumitomo Electric Networks Co., Ltd. (NWX), which had been in charge of broadband access network products (EPON, xDSL, STB) business for telecommunication carriers since 2002, and Broad Net Mux Corporation (BNMUX), which had been in charge of the products and system integration business for CATV operators in Japan since 1995, and integrated them into the Broad Networks Division of Sumitomo Electric in 2014. Since 2015, the Company has pursued synergies in its three portfolios of network products, video (STB) products, and CATV systems.

After its 10G-EPON OLT (for stations and headend) and ONU (for home premises) received the world-first qualification for DPoE (Data Over Cable Service Interface Specification (DOCSIS) Provisioning over EPON) 1.0, which enabled the adoption of IEEE EPON products to CATV's IP network, from CableLabs (Cable Television Laboratories, Inc. in the US) in 2013,[17] the Company had been focusing on the development of 10G-EPON systems for US CATV MSOs, and started shipping to them in 2015[18]-[20] (Photo 1). Utilizing this achievement, Sumitomo Electric contributed to the standardization of 10G-EPON at Japan Cable Laboratories (JLabs), and provided a line-up of customized 10G-EPON products with common hardware and middleware platforms for domestic telecommunications carriers (such as NTT Group and Power Nets Japan Group), North American CATV MSOs, and domestic CATV operators. In March 2018, the Company also licensed its EPON product technology and transfer the EPON businesses in North America to a partner, ADTRAN, INC. in the United States and started the OEM supply.[21]

The Company has also developed a lineup of servers in-house, including the IP broadcasting servers for BS digital, terrestrial digital, advanced BS, and multi-channel broadcasting services of CATV operators, as well as the IP-retransmission servers for telecommunication carriers (Photo 2), and contributed to the standardization of them.

As a result, Sumitomo Electric provided end-end solutions combined with 10G-EPON and 4K/8K products (servers and STBs) to each market. It became two wheels of the Company's broadband access business during this period.

## 4. Technology Trends for 3D and XR Video Distribution Services

One of the big opportunities for the next-generation video distribution market following 4K/8K is 3D and XR video distribution services that use head-mounted displays (HMDs), XR glasses, or 3D flat panels as the client display devices and connect to the edge servers in the cloud. Domestic shipments of HMD and XR glasses are expected to grow approximately 2.7 times in 2025 from the 380K units of achievements in 2022.[22]

There are several technologies to display 3D/XR videos, however, the one that is becoming the mainstream at this moment is the technology to make two 2D viewports videos to be rendered for each eye of the client from the 360° 3D/XR virtual space information, based on the "eye-tracking and XR sensor information," which consists of the direction of the eye (called 3DOF (3 Degrees of Freedom)) and spatial position of the head (in total 6DOF). 3DOF/6DOF information is measured in real time by using LiDAR, image sensors and so on, which are built into HMD, XR glasses, or 3D flat panel displays including their peripheral devices.

The function to render 2D images in the XR display area from 3D space information based on the sensor information can be performed in, (1) the user's XR device (display or nearby Box), (2) the XR server on the network cloud, or (3) the hybrid of them. Each has pros and cons, and the contributor has no intention to choose one. However, as an example, Fig. 6 shows a functional architecture of the above case (2) "viewport rendering in network," referred from the technology report (3GPP TR).[23] Architecture (2) is expected from the point of view of minimizing the size, weight, power consumption, and complexity of the XR devices for the client.

In XR video services, it is required to minimize a new key performance indicator (KPI), which is not found in conventional 2D video services. This is called "Motion-to-Photon (MTP)" latency, a round-trip delay time until the image is displayed, corresponding to the movement of the head and eye-sight, as described in Fig. 5. The permissible maximum MTP delay for the immersive experience without feeling cyber sicknesses (of human brain's visual cortex) varies depending on various conditions including lighting, change of senary and so on, however it has been discussed in the range of 5 msec to 20 msec.

Photo 1. 10G-EPON OLT (FSU7100 series)

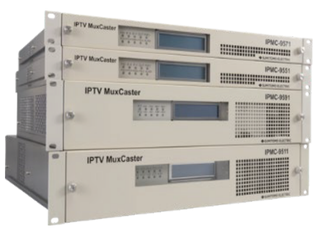



Photo 2. IP4K / 8K Broadcast / Multicast Servers (IPTV MUX Caster series)

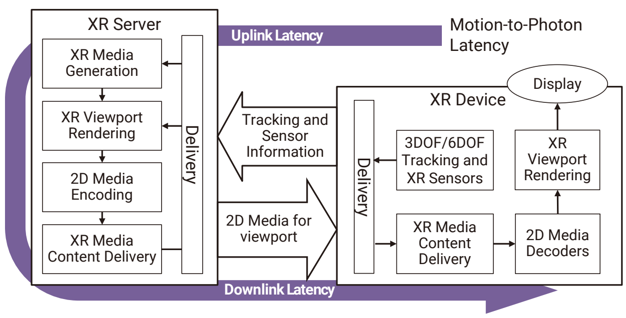



Fig. 5. XR Processing and Media Centric Architectures for Viewport Rendering in Network (Originally created drawing with reference to Section 6.2.4 of (23))

IOWN Global Forum's AI-Integrated Communications Use Case Release-1[24] and the "viewport rendering in network" in the aforementioned 3GPP TR specify ≤ 10 msec as a requirement.

Figure 6 shows the reliability (packet error rate) and latency (packet delay budget) required for various services on 5G and beyond 5G communications, extracted from the 3GPP TR mentioned above. It can be seen that the permissible packet delay time of 10 msec for augmented reality (AR), one of XR applications, is more than one order more critical than the permissible delay for various conventional services including 2D video. It should be noted that the video compression technologies shown in Table 1 cannot be applied with a high compression rate in order to achieve MTP latency ≤ 10 msec. This is because the video codec with a high compression rate needs frame buffer(s) to calculate the gap between the video frames so that a delay on the order of half to several times of the video frame length occurs at each node or terminal. The delay caused by buffering, which is equivalent to one frame is 33.3 msec, 16.7 msec, 8.4 msec, and 4.2 msec when the frame rate is 30 fps, 60 fps, 120 fps, and 240 fps, respectively. Raising the frame rate will improve the delay, however, the XR server's CPU, GPU load, power consumption, and network traffic will also increase.

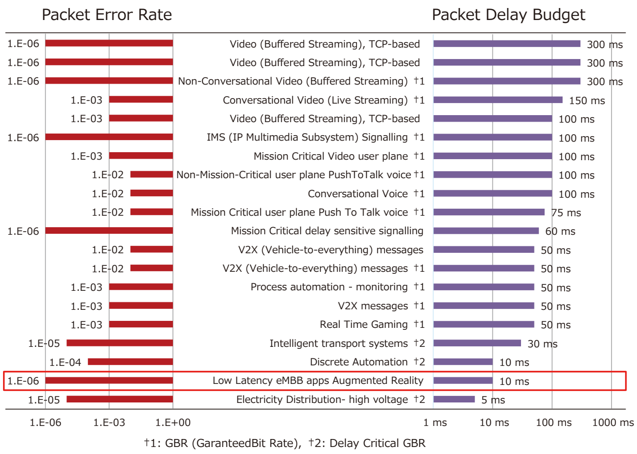



Fig. 6. QoS (reliability and latency) mapping for applications expected in 5G/B5G
(An original graph of the data from Table 4. 3. 3-1 in reference[23])

## 5. Conclusion

This paper has overviewed the growth of communication traffic in access lines corresponding to the quality of video content and the progress of video compression and distribution technology, and described Sumitomo Electric's technology development and commercialization efforts. In the future, new 3D XR video distribution services that use displays with local eye-tracking functions and XR computations in the cloud using AI are expected to grow, and these new services will drive the increase in the required transmission bandwidth shown in Fig. 1 and Eq. (2).

In order to realize these new services, extremely small MTP latency and reliability are required for the communication between the XR server in edge DC and local clients, and low-latency transmission including uncompressed or light-compressed video communication, which consumes large traffic must be realized.

It is expected that in the future, next-generation information and communication infrastructure will be developed in combination with cloud AI computing and all photonic network and/or B5G/6G mobile network, and the low-latency, high-speed and high energy efficiency features of this infrastructure with the combination of 3D and XR technologies will be the growing market not only in entertainment but also in medical surgery, smart cities, transportation systems, industrial sectors, and various other segments. In response to this, the Company is willing to contribute to part of this evolution by developing multicore optical fibers, wavelength-tunable optical devices, wireless communication devices, all-photonic and wireless network products, gateway products with deterministic networks, small and low power consumption communication terminals, and low-latency video distribution terminals.



### Technical Term

*1 XR: Cross reality or extended reality is a generic term for technologies that create new experiences by the fusion of the real world and the virtual world, such as virtual reality (VR) , augmented reality (AR), mixed reality (MR), and substitutional reality (SR).

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