In this report, we aim to present the latest updates in our research and developments on the transmission of audio and video signals over wired networks. We will start by reviewing the progress we have made so far, then describe in detail the technologies for delivering video directly to the home via cable television and the internet. We will also look at IP and other new technologies in the field of program production and contributions to it.

1. NHK STRL’s Research and Development on Wired Transmission Technologies

Terrestrial and satellite broadcasting services use radio waves to deliver programming to each household. On the other hand, cable television (CATV) services distribute programming over coaxial cables and other wired networks. CATV emerged before the advent of digital broadcasting and has seen much growth, especially in areas where over-the-air reception is limited. More recently, watching high-quality video via fiber-optic internet connection has also been gaining ground. On the contribution side, broadcasters are now starting to use optical fiber and the public internet to transmit their video material, in addition to conventional transmission over radio waves. See Figure 1 for a breakdown of wired transmission technologies used in and around broadcasting.

Since the 1980s, when tests on satellite and analogue HD broadcasting had just begun, the STRL has been conducting research and development on video transmission technologies using fiber-optic cable. In order to promote satellite broadcasting, we established a transmission system whereby CATV facilities receive satellite signals, convert them to intermediate frequency (IF) signals, and distribute them to each household via optical fiber. We have also made progress in transmitting major sporting events over optical fiber to enable live public HD screenings at remote venues. These research studies were mainly focused on finding technical solutions to issues in converting analogue electrical signals into optical signals so that they can be transmitted over fiber-optic cable.

In the 1990s, HD program production began moving towards digitalization. We started working on technologies to send uncompressed digital HD signals over long-distance optical fiber at a speed of 1.5 Gbps, which was very fast at the time. We were also looking at how to send digitally modulated radio frequency (RF) signals over CATV, in anticipation of the upcoming digitization of satellite broadcasting.

In 1995, we set out to develop a new audiovisual system with higher video resolution than HD, and as we entered the new millennium, our R&D on 8K Super Hi-Vision (8K UHD) was fully implemented. We also started studying 8K CATV broadcasting and technologies for transmitting uncompressed 8K material over optical fiber for program production purposes.

In order to transmit full-specification uncompressed 8K signals, we need a transmission speed of around 144 Gbps. This is roughly a hundred times faster than HD transmission, which raises considerable challenges in developing compatible equipment and enabling long-distance transmission. We decided to take advantage of the technological achievements made in the field of communications and to apply Ethernet technology that had already been in wide use for data transfer.

All of the above studies relate to improving signal formats between transmitters, or enhancing their transmission properties. If we look at it in terms of the Open Systems

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Figure 1: Wired Transmission Technologies in Broadcasting
Interconnection (OSI) reference model, often mentioned in data communication, we may say that these research studies have been centered mainly on the first layer or the physical layer. (Figure 2)

By around the year 2000, wired high-speed broadband services had emerged, serving customers via telephone and CATV networks. Optical fiber services followed, providing broadband access to consumers while boosting internet speed. Mobile broadband services started promoting devices that are compatible with 3G (third-generation wireless mobile telecommunication technology) or later. The STRL kept pace with these trends by embarking on R&D on streaming technologies to offer video over the internet to complement programming over the air.

We also started investigating a new hybrid service that integrates broadcasting and communication using MPEG media transport (MMT), an industry standard to multiplex video, audio, and data for the advanced digital satellite broadcasting system. These studies are based on the premise that the physical layer, which in this case is the transmission circuit, is already available as part of the infrastructure. It means that our research on wired transmission technologies has broadened its scope to cover a wider range of layers (in terms of the OSI reference model referred to above).

In the following sections, we discuss the latest developments in our research on wired transmission technologies. In Section 2, we look at CATV transmission; in Section 3, we discuss streaming video over the internet. In Section 4, we talk about uncompressed 8K transmission as well as IP transmission for video contribution, and in Section 5, we explain more about MMT.

2. CATV Transmission

According to figures by the Japanese Ministry of Internal Affairs and Communications, CATV penetration in Japan is now over 50%. It has become an important part of the communication infrastructure for NHK as well, as a means to deliver its programming to even more households. Beginning in the days of analogue broadcasting, the STRL has been doing research on CATV transmission technologies to distribute programming with the same high quality as over the air.

The current CATV system comprises a “headend,” a transmission network that includes trunklines and service drops, and a reception device at individual subscriber homes. A headend is a regional facility for cable companies to receive over-the-air television signals and distribute them together with their own programming over the CATV system. (Figure 3.) The conventional standard was to use coaxial cable throughout the entire system. However, systems like the hybrid fiber coaxial (HFC) distribution, which uses optical fiber for trunklines and coaxial cable for service drops, and fiber-to-the-home (FTTH), where both the trunklines and service drops are fiber, have become more common.2)

A single-carrier 64-QAM modulation scheme was initially adopted as the modulation standard for domestic digital cable television transmission. This scheme was in line with the European standard3) except for the roll-off factors and transmission rates. Later on, the 256-QAM modulation scheme was standardized following further consideration on multi-valuing.4)

In developing a 4K and 8K transmission technology that is compatible with both the HFC and FTTH systems, ideally it will be a method that can operate alongside traditional digital transmission and not require changes to the existing framework. One way to transmit high-capacity signals using the current digital broadcasting modulation scheme is to combine multiple channels. In 2000, the Telecommunications Advancement Organization (TAO, predecessor of the current National Institute of Information and Communications Technology/NICT) proposed a multiplexing method5) using a frame configuration called Transport Stream Multiplexing Frame (TSMF)6), which was adopted for digital cable broadcasting. However, because this method requires all the channels to be running at the same transmission speed, it was not always compatible with the 256-QAM scheme. Thus, we proposed a method that allows multiplexing channels at different speeds7). We also proposed a multiplexing scheme to enable the transmission of MMT.
and other variable-length packets in addition to traditional MPEG-2 Transport Stream (TS) signals.\(^3\)

We submitted our proposal to the Working Group on Advancing Cable Transmission (ACT-WG) at the Japan Cable Television Engineering Association (JCTEA). The ACT-WG set up a task force and conducted a series of verification tests to assess the practicality of the method and its consistency with various requirements, such as high transmission rates and flexibility in multiplexing services.\(^9\) The assessment was reflected in discussions by the CATV UHDTV Working Group of the Broadcasting System Subcommittee under the Department on Information and Communications Technology of the Information and Communications Council. As a result, a report on the UHDTV technical requirements for cable television was submitted, which led to the formulation of technical standards.

We are also looking into baseband optical distribution systems (henceforth, “baseband method”) as a potential option for FTTH networks. The baseband method involves combining 8K or HD baseband signals using time-division multiplexing (TDM), which will reach around 10 Gbps, and transmitting it over optical fiber. In conventional subcarrier multiplexing (SCM) transmission for FTTH networks, light intensity is modulated using a Frequency Division Multiplexing RF signal. The baseband method, on the other hand, modulates light intensity binarily, meaning either ON or OFF. This enables a simple structure and requires only a low signal-to-noise (S/N) ratio, which will help in
bringing down the cost of distributing high-capacity signals over optical fiber. We compared SCM and optical baseband transmissions in a modelled scenario, where both systems distribute an equal amount of data to the same number of households in the same area. It revealed that the baseband method can reduce the number of optical amplifiers by about 20% compared with SCM. With the recent availability of high-speed 10G Ethernet, we have developed a test device for baseband FTTH digital distribution to evaluate the transmission properties of the MPEG-2 TS signal. We now have a good prospect of establishing a system to distribute multiple channels to each home, just as we do with SCM. See Figure 4 for the configuration of the test device.

3. Video Streaming over the Internet

With broadcast and broadband coming closer together, NHK has been working on creating services to deliver more programming and contents to a wider audience using the internet. The STRL is researching technologies for a stable, large-scale distribution of video. In this section, we will first look at the MPEG-Dynamic Adaptive Streaming over HTTP (DASH) player that we have developed at the STRL, followed by the latest progress on our research on stable distribution technology using the player.

Conventional media players for watching Internet video on television, computer, and mobile devices are all based on different technologies. This required the distributors to set up separate facilities for each system, and cost reduction and streamlining were the major challenges. The STRL developed an MPEG-DASH player, a common player that can be used on the web browser and serves as a uniform video distribution platform for computers and mobile devices, including smartphones (Figs. 5 & 6). This player uses the streaming technique “MPEG-DASH,” which has been jointly adopted as the international standard by the International Organization for Standardization and the International Electrotechnical Commission (ISO/IEC), and can be used with browsers supporting HTML5, the latest version of the markup language for the web. It also complies with the operational regulations on Hybridcast laid out in December 2014 by the IPTV Forum Japan, the domestic body that formulates the technical specifications regarding IPTV in Japan. It means that users will be able to switch between broadcast signal and streamed video-on-demand (VOD) when using Hybridcast, the integrated broadcast and broadband service in Japan.

We have been researching how we could use this MPEG-DASH player to establish a stable and reliable distribution technology. One potential is to install a function that monitors the reception of the video signal on the receptor device and reports it back to the distributor. The distributor can analyze this data to dynamically alter individual distribution paths accordingly, in order to avoid heavy traffic and concentrated access to the server. We are also studying ways to ensure stable and reliable streaming of video on television and other devices that are generally equipped with smaller memories and low-performance CPUs.
pared with computers. To this end, we have conducted laboratory testing to identify the problems behind the current browser system. Together with other commercial broadcasters, we have raised the issue\(^{16}\) to the Web and TV Interest Group at the World Wide Web Consortium (W3C), the international body for web standardization.

IPTV Forum Japan has been working on establishing a reliable streaming environment by ensuring compatibility between different systems using the MPEG-DASH technique. The Forum regards the MPEG-DASH player as its standard player.

4. Contribution Technology
4.1 Uncompressed 8K Contribution Technology

In HD program production today, video signals are uncompressed throughout the production chain, from camera to monitors and editing suites, in order to ensure high quality and low latency. 8K video has approximately 33 million pixels, or 16 times more pixels compared with HD. Ideally, 8K production and transmission equipment should offer broadcasters the ability to evolve their facilities later on to handle uncompressed signals, just like they do with the current HD systems. To make this possible, the STRL is working on technologies to transmit uncompressed 8K signals using optical fiber. Potential applications include facilities for the exchange of 8K video material between multiple points within a broadcasting station, and long-distance unilateral transmission facilities to send material to the station from the crew on site (Figure 7). Transmission may involve so-called “dark fiber” or unused optic fiber no longer than about 300 km, or longer-distance networks provided by communications operators.

As a basic study, we looked into how we may apply network communications technology such as the Local Area

![Figure 6: Play-out using MPEG-DASH Player on various devices](image)

![Figure 7: Applications of Uncompressed 8K Optical Transmission](image)
Network (LAN) and Storage Area Network (SAN) to the transmission of uncompressed 8K signal. For the years 2007–2011, we were commissioned to undertake the project “The Next Generation High-Efficiency Network Device Technology Development” by the New Energy and Industrial Technology Development Organization (NEDO) to develop an ultrahigh-speed LAN–SAN system for 8K distribution inside broadcasting stations. In this system, $4 \times 40$ Gbps optical transmission frames called Optical Channel Transport Unit-3 (OTU3) are bundled into one 160 Gbps signal using Optical Time-Division Multiplexing (OTDM). We have prototyped an experimental device that can efficiently multiplex uncompressed 8K signals into OTU3s. Evaluation tests have given us good results.

Then came the 100 Gbps Ethernet, which is much faster than the 40 Gbps OTU3s. It is expected to lower the prices of relevant equipment, so we decided to use this Ethernet technology to develop a new system. In conventional in-house networks within a broadcasting station, high-speed signals such as uncompressed HD had been transmitted over a dedicated system, independent from the Ethernet network handling file data from servers. However, we are starting to see an increased use of 10 Gbps Ethernet for the transmission of uncompressed HD. With 100 Gbps Ethernet, we will be able to establish an efficient integrated in-house network for local 8K transmission. Our studies so far include frame conversion technology for the transmission of 72 Gbps uncompressed, full-resolution 8K signals over 100 Gbps Ethernet, methods to control the video clock on the receiving end for a reliable and low-latency transmission, and measures against packet loss. We are also working on transmitting 144 Gbps uncompressed, full-specification 8K signals over two 100 Gbps Ethernet networks.

One of the challenges in using dark fiber for transmission is the amount of time and money needed to install an erbium-doped fiber amplifier (EDFA) every few dozen kilometers over the entire network. This has led us to look into the possibility of using distributed Raman amplifica-
tion (DRA) in which the optical fiber for transmission also serves as the amplifier. We conducted an experiment to send full-resolution 8K signals over a distance of 300 km without a relay station, and we have concluded that using DRA enables us to send the signals 100 km farther than without DRA.\(^{23}\) The full-resolution 8K signals in this case were multiplexed, bringing two 43 Gbps optical signals into one using return-to-zero differential quadrature phase-shift keying (RZDQPSK) modulation.

Another issue with developing a transmission network using dark fiber is the interface compatibility between equipment. In March 2014, the Association of Radio Industries and Businesses (ARIB) in Japan set out the standard ARIB STD-B58 (“Interface for UHDTV Production Systems”). It is an interface (I/F) standard designed for the transmission of ultrahigh-resolution television signals between studio equipment, and as such, only envisions short-distance transmission. We need to establish a system that conforms to this standard but is able to transmit uncompressed, full-resolution 8K signals over longer distances. We therefore developed a method of incorporating error-correction codes (ECCs). Through a series of lab testing, we found that the ECC method can extend the transmission distance by more than 20 km compared with the non-ECC method. We conducted further tests with the National Institute of Advanced Industrial Science and Technology (AIST). Using a single-core optical fiber and optical amplifiers, we were able to successfully transmit a 72 Gbps uncompressed, full-resolution 8K signal between STRL in Tokyo and the AIST facility more than 173 km away.\(^{24}\) See Figure 8 for the configuration of this experiment.

4.2 Using Wired IP Technology for Wireless IP Transmission Underwater

The STRL has made progress in R&D on wired IP transmission technologies that adjust the video compression rate according to how heavy the network traffic is.\(^{25}\) We are now working on applying this technology to wireless IP transmission in order to establish a reliable method of sending video over the types of network that may be affected by external factors, changing the transmission speed dramatically. In this section, we will discuss wireless IP transmission underwater. It is a very challenging environment for wireless transmission, but the STRL has succeeded in developing a wireless method to send live video from underwater cameras (Figure 9).

Radio waves are greatly affected in water and is virtually impossible to use for wireless transmission. That is why conventional live transmission from underwater has been carried out using long camera cables. However, camera cables can be pushed around by waves and tides, causing serious safety hazards. Producers need to have several divers to secure the cable and ensure safety underwater.

Our newly developed underwater transmission system eliminated camera cables by using blue visible light, which is less affected by water. We have also developed a system to automatically optimize the transmission rate to ensure that the IP transmission is suitable for live transmission, even if it is obstructed by occasional fish or by seaweed in the water. When the transmission light is temporarily disrupted and results in loss of data, the receiver automatically sends a request for a prioritized retransmission of missed-out data to ensure stable transmission.

The following is the description of how the adaptive transmission rate control (ATRC) works in wireless underwater IP transmission.

1) Error correction code is added to the video from the underwater camera before being sent over to the wireless transmitter (Figure 10(a)). Minor errors such as those caused by a slight deviation of the optical axis can be corrected with the error correction data.

2) When the transmission is temporarily but totally disrupted by an obstacle, the video data is lost and becomes uncorrectable (Figure 10(b)).
When the obstacle moves on and transmission is resumed, the transmission rate for the ongoing video and error correction code is lowered, allowing time to resend the lost data. Retransmission of the lost data is given priority to minimize the break in video transmission (Figure 10(c)).

We conducted a simulation test using a network simulator to see how well the ATRC works when the wireless transmission is disrupted (Figure 11). We used H.264/Advanced Video Coding (AVC) and Advanced Audio Coding (AAC) for video and audio coding, respectively, and User Datagram Protocol/Internet Protocol (UDP/IP) for transmission. We allocated a total maximum transmission rate of 48 Mbps for video, error correction, and retransmission data. Video data rate was varied between 3–8 Mbps depending on the condition of the transmission, allowing the rest of the data rate to be allocated for error correction and retransmission.

The result of the simulation test is shown in Table 1. The IP Packet loss rate refers to the rate of packets lost out of all the UDP/IP packets and indicates the loss rate for the transmission circuit. The Media Packet loss rate is the rate

<table>
<thead>
<tr>
<th>Duration of Disruption</th>
<th>Duration of Transmission</th>
<th>IP Packet Loss Rate</th>
<th>Media Packet Loss Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 ms</td>
<td>600 ms</td>
<td>25%</td>
<td>0.0%</td>
</tr>
<tr>
<td>400 ms</td>
<td>400 ms</td>
<td>50%</td>
<td>0.0%</td>
</tr>
<tr>
<td>600 ms</td>
<td>200 ms</td>
<td>75%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Figure 10: Optimizing Transmission Rates in Underwater Wireless IP Transmission

Figure 11: Configuration to Test Performance of the Transmission Rate Optimization

Table 1: Results of the Transmission Rate Optimization Test

*1 SDI: Serial Digital Interface
*2 UDP/IP: User Datagram Protocol/Internet Protocol
of loss after ATRC as well as retransmission of any packet initially lost, so a media packet loss rate of 0.0% indicates there is no disruption in the video.

Table 1 shows that if the IP packet loss is less than 50%, the media packet loss is 0.0%. In other words, we now know that if we can keep the packet loss of the transmission network to less than 50%, we can do live transmission from underwater without video disruption.

5. R&D on Media Transport Methods and their Standardization

5.1 R&D on Transmission Technologies using MMT

MMT is a standard for multiplexing broadcast and/or communication streams for the distribution of contents. It specifies the requirements on various components, including the video and audio formats, media transport protocol, and signaling information messages that indicate the structure of the content. Coordinated Universal Time (UTC) is used for the management of presentation time, enabling services that require receivers to synchronize multiple video and audio feeds delivered via different distribution paths.

The Moving Picture Experts Group (MPEG), a working group under ISO/IEC, set out to develop and standardize MMT in 2009. NHK has been participating in its discussions from the beginning, while also working on the standardization of 4K and 8K satellite broadcasting, which began test broadcasting in August 2016. We have also been prototyping relevant hardware to conduct various verification tests.

During the annual STRL Open House in May 2015, we conducted a public 8K satellite broadcasting experiment (Figure 12). 8K video multiplexed at NHK’s broadcasting center using MMT was transmitted via the BSAT-3b broadcast satellite and received at the STRL. The demonstration also featured a CATV transmission scheme that receives and retransmits MMT multiplexed 8K programming.

Also during the 2015 Open House, we demonstrated two potential hybrid services, multiview and targeted program promotion, as part of a test transmission using equipment conforming to ARIB standards. The Japanese telecom NTT provided the optical fiber network testbed called GEMnet2 while CATV Jupiter Telecommunications (J:COM) contributed its hybrid fiber-coaxial (HFC) network for the test (Figure 13).

A multiview service offers additional, synchronized video over the internet to complement the main broadcast programming. The complementary content may be video from an alternative angle. In the demonstration, the main 4K video was transmitted from the MMT “master” server located within the STRL, went through a pair of satellite modulator and demodulator, and was received by the MMT receiver “A”. The 2K complementary video was transmitted from the MMT “slave” server located at a separate J:COM facility. It goes through the distributor modem called cable modem termination system (CMTS), J:COM’s HFC network, the receiver’s modem, and finally to the same MMT receiver “A”. (The signal is converted to Data Over Cable Service Interface Specifications (DOCSIS) 3.0 when going through the HFC network). The MMT receiver “A” was able to refer to the UTC timestamp multiplexed in both the main and complementary videos to synchronize the two and provide a multiview experience.

![Figure 12: Overview of 8K satellite broadcasting experiment](image-url)
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The other example of hybrid services demonstrated at the Open House was the targeted program promotion. It uses user data stored in the receiver, such as gender, age, and program preferences, to show viewers either the main programming broadcast over the air or the alternative programming sent via broadband. For the test (Figure 13), the main programming from the master MMT server at STRL was transmitted via the same path as the main multiview video, then received by the MMT receivers “B” and “C”. The alternative programming was sent from the same master MMT server but was switched out to go through the GEMnet2 network, finally reaching the MMT receiver “C”. Receiver “C” was able to refer to the UTC timestamp muxed on both the main and alternative programmings, replacing the main programming with the alternative without any glitches.

5.2 Standardization of Media Transport Methods

In Japan, MMT has been adopted as the transport method for the 4K and 8K satellite broadcasting, which started test broadcasting in August 2016. Its standard, the ARIB STD-B60, was set out in July 2014. In December 2015, the Next-Generation Television and Broadcasting Promotion Forum (NexTV-F) published a volume of technical data as operational guidelines (NEXTVF TR-0004 ver. 1.0). Internationally, MPEG has been working on the standardization of a media transport method suitable for the IP network environment. The work began in 2009 and MMT was designated as an international standard in March 2014. It was followed by the publication of the Implementation Guidelines by the ISO in February 2015, in which Japan’s 4K and 8K broadcasting system is referred to. In parallel to this move, the International Telecommunication Union Radiocommunication Sector (ITU-R) adopted a new recommendation in June 2015, referring to the Japanese ARIB STD-B60 in detail. In the United States, the nonprofit organization Advanced Television Systems Committee (ATSC) has been working on the development and standardization of the next-generation terrestrial television system, ATSC 3.0, since September 2011. A protocol stack is expected to be adopted in the near future, which would specify MMT and DASH/ROUTE* in its transport layer.

6. Summary

In this report, we detailed the transmission technologies that the STRL has been working on to transmit video and audio signals over wired networks. While R&D on terrestrial and satellite broadcasting takes a holistic approach and aims to enhance everything from transmission to delivery based on the spectrum allocated for broadcasting, R&D on wired transmission stands on the basis that relevant infrastructure is already there. In other words, it needs to consider how to implement broadcasting services onto existing infrastructures such as CATV, the internet, and communications networks. Technologies around these infrastructures evolve extremely fast. We intend to keep up with their development and work on our own R&D to deliver even better services to our audiences.

* ROUTE: Real-time Object Delivery over Unidirectional Transport
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