6-Gbit/s Uncompressed 4K Video IP Stream Transmission and OXC Stream Switching Trial Using JGN II

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Abstract

A trial of the transmission of an uncompressed 4K video IP (Internet protocol) stream was conducted at the JGN II Symposium in Sendai, Japan, on January 18, 2006. Video images with four times the resolution of HDTV (high-definition television) were used to evaluate the feasibility of next-generation video production environments and relay services. In this article, we outline the trial and present its results.

1. Background

In the field of video transmission, the move toward high-definition and high-quality video presentation has been accelerating in recent years as image processing technology has advanced and broadband networks and high-capacity storage devices have become mainstream. The term "4K video" refers to a video image consisting of 4096 × 2160 pixels, which is about four times the resolution of HDTV (high-definition television). This level of resolution is attracting increased attention, and it has been adopted as the top standard in the Digital Cinema System Specification [1] of Digital Cinema Initiatives, LLC. NTT developed the world's first 4K video transmission technology using the JPEG 2000 encoding method. This technology has been well received and was incorporated into the digital cinema specifications [2]. Application of 4K video is not restricted to digital cinema—it is expected to be used for high-quality broadcasting services of sports matches, concerts, and other events and in various fields including remote education. However, when 4K video is used for realtime applications such as live broadcasts and videoconferencing, or for video production, which requires extremely high-quality picture, video encoding/decoding delays must be minimized. Furthermore the video must be transmitted "as-is" in uncompressed form. Against this background, we conducted the world's first trial of uncompressed 4K video transmission over an actual IP (Internet protocol) network using JGN II*1 at the JGN II Symposium in Sendai, Japan, held on January 18, 2006. Our objective here was to evaluate the feasibility of uncompressed 4K video IP stream transmission technology and of next-generation video services.

2. Overview of the trial

In this trial, we used live video taken by a 4K digital video camera at Keio DMC (the Keio University Research Institute for Digital Media and Content) in Mita, Tokyo, and 4K digital cinema material stored on an uncompressed 4K video server at NTT Musashino R&D Center. Each source video in uncompressed form was converted into IP packets and transmitted to the symposium hall as a 6-Gbit/s stream over JGN II and presented using a 4K liquid-crystal projector. The system configuration is shown in **Fig. 1**. The network had a bandwidth of 10 Gbit/s.

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*1 JGN II: An ultrahigh-speed, high-performance open testbed network for research and development that began operating under the National Institute of Information and Communications Technology (NICT) in April 2004 as an enhancement to the original JGN (Japan Gigabit Network) that operated up to March 2004 [3].

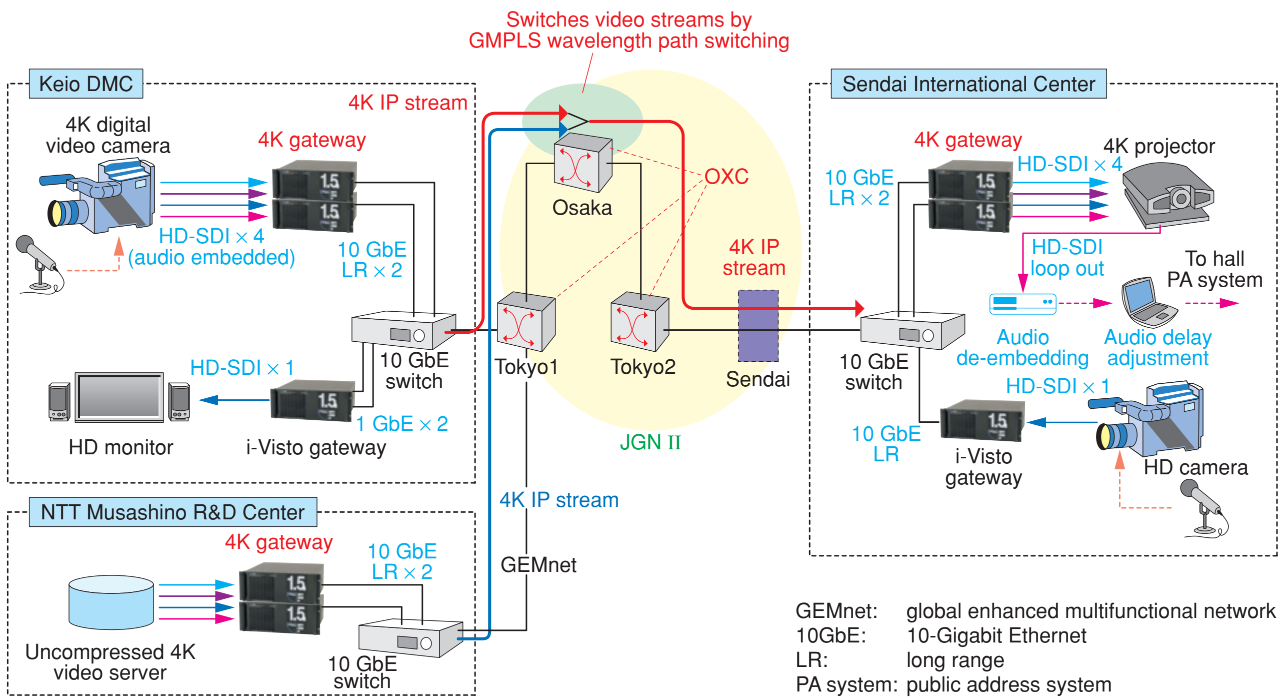

Fig. 1. System configuration of the uncompressed 4K video transmission trial.

In this trial, the system switched video streams from the two sources by switching wavelength paths*2 using an optical cross connect on the network.

3. IP stream transmission of uncompressed 4K video using 4K gateway

3.1 Overview of 4K gateway

The IP stream transmission of uncompressed 4K video in this trial was performed using a newly developed 4K gateway based on the i-Visto gateway [4], [5] developed by NTT (**Fig. 2**). The i-Visto gateway is a system that takes HDTV video signals input via HD-SDI (high-definition serial digital interfaces), transforms them into IP packets in real time, and transmits IP video streams in uncompressed form (**Fig. 3**). The 4K gateway has four HD-SDI processing boards and two 10-Gbit Ethernet (10-GbE) interfaces. First, the system divides one frame of 4K video into four 2K images, inputs that frame as four synchronous HD-SDI signals, and converts each of those four signals into an IP-packet stream. The bit rate of each of these streams is 1.5 Gbit/s. One 10-GbE interface transmits two streams using UDP/IP (UDP: user datagram protocol). The outputs from two Ethernet interfaces are then aggregated by one 10-GbE switch resulting in a stream with a total bit rate of 6 Gbit/s output to the network.

*2 Wavelength path: A gigabit-class high-speed optical circuit deployed between optical cross connects (OXCs) that can guarantee communication quality with a high degree of privacy by monopolizing a single wavelength.

Fig. 2. 4K gateway.

3.2 4K video stream synchronizing function

At the time of input, the four HD-SDI signals are clock synchronized so that they can be regarded as a

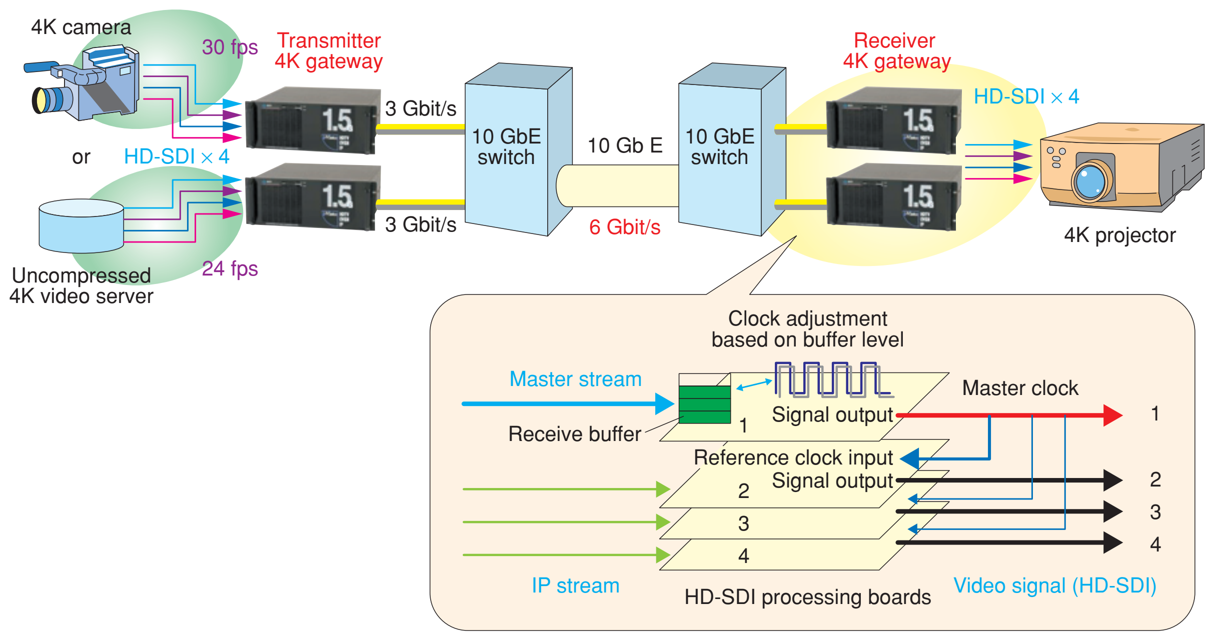

Fig. 3. Transmission system using 4K gateway.

single video signal. However, during network transmission, there is no means of performing clock level synchronization between individual streams. Therefore, there is no other choice but to handle them as separate independent video streams. Consequently, the four streams must again be clock synchronized on the receiver side so that a video display device can recognize them as one video signal. The 4K gateway on the receiver side converts the received IP stream into four HD-SDI signals and then creates one master video stream from them. A master video clock is regenerated from the master video stream with an HD-SDI processing board. Each of the other three HD-SDI interfaces inputs this master clock as the reference clock, synchronizes with it, and plays back the IP stream, resulting in four synchronized streams of HD-SDI signals in total that can now be shown as 4K video.

3.3 Remote clock synchronization of 4K video

In the above discussion, the clock of the video signal on the transmit side and the clock of the video signal on the receive side are independent of each other. This means that the frequency mismatch of the video clocks can accumulate if streaming is of long duration, leading to buffer underflows or overflows on the receive side. This problem is commonly solved by redisplaying or skipping a video frame. In contrast, the i-Visto gateway monitors changes in the buffer level on the receive side to detect the clock mismatch and dynamically changes the clock frequency on the receive side to perform remote clock synchronization between the transmitter and receiver. In the 4K gateway, this function is actually applied only to the master stream, but since the other three streams fall in line with the master stream as described above, remote clock synchronization is, in effect, applied to all streams.

4. Video stream switching by OXC

Since the bit rate of an uncompressed 4K video stream is 6 Gbit/s, only one stream can be transmitted at one time on a network with a bandwidth of 10 Gbit/s. An application is therefore needed that can select and play back one of several 4K video sources located at remote points. Such an application can be achieved by either transmit start/stop control directed at transmit-side 4K gateways handling the video sources to be switched or by a mechanism that switches the stream to be relayed at nodes on the transmission path.

In this trial, we installed optical cross connects (OXCs) at two locations in Tokyo and one location in Osaka and interconnected them to form the transmission path denoted as Tokyo1-Osaka-Tokyo2-Sendai having a total length of 1500 km. We switched streams by switching the wavelength path of the

Tokyo1-Osaka segment.

An OXC has a function for changing the direction of a wavelength-multiplexed optical signal in units of wavelengths [6]. Combining this function with generalized multiprotocol label switching (GMPLS) enables flexible wavelength-path setting in accordance with user needs while enabling transmission-path switching without affecting the optical transmission bandwidth.

5. Experimental results

We began the trial by delivering live video taken by a 4K camera set up at Keio DMC and holding a videoconference with Sendai International Center (**Fig. 4**). The video from Sendai International Center was taken by an HD camera and transmitted to Keio DMC via an i-Visto gateway.

Next, by manipulating the OXC at the Tokyo1 location using RSVP-TE*3 (resource reservation protocol with traffic engineering) signaling of GMPLS, we switched the wavelength path of the Tokyo1–Osaka segment to deliver 4K digital cinema material from NTT Musashino R&D Center to the hall. The 4K live video was played back at 30 frames per second (fps) and the 4K digital cinema material was played back at 24 fps.

The 4K-gateway remote clock synchronization function was used to perform video transmission with no frame dropping. The clock frequency on the receive side could be changed only within the range allowed by the HD-SDI standards, so the buffering level at the beginning of transmission was enough to prevent buffer under/overflow. The frequency was then changed a little at a time until the amount of data in the buffer converged to a certain level and stable operation could be observed.

In general, it has not been possible to prevent a delay of the time length of several video-frames over the entire system due to the effects of internal buffers in the 4K digital video camera and 4K projector. However, the delay generated at the 4K gateways and by network transmission is very small (less than one frame), so we were able to hold a natural conversation in the 4K videoconferencing trial. Visitors to the hall praised the uncompressed 4K video content as beautiful and expressed admiration for the videoconferencing demonstration.

*3 RSVP-TE: Label-switching technique using MPLS employed for QoS assurance and high-speed rerouting. It enables flexible path setting by conveying dynamic path information.

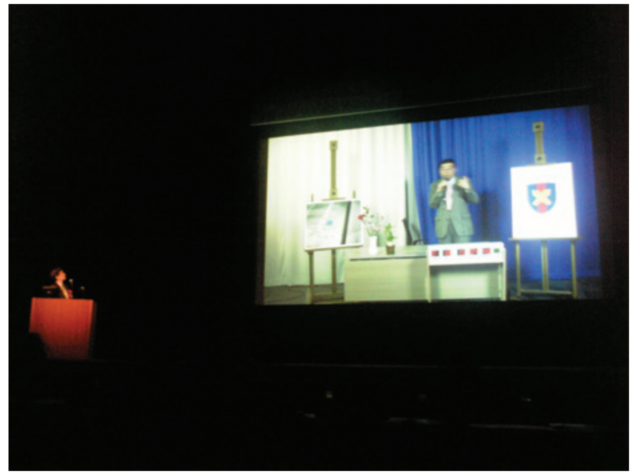

Fig. 4. Example of 4K videoconferencing (Sendai International Center).

6. Future developments

We intend to improve the performance and operability of GMPLS and OXCs to establish stream-switching technology on layer 3 and a 4K video editing scheme between remote points. We also intend to create ultrahigh-speed network services toward next-generation video-content production featuring the seamless editing and use of super-high-definition video material located at multiple production points and broadcast stations.

Part of this trial was conducted in conjunction with the “Research and Development of Next-generation Video Content Production and Distribution Technologies” program of the Ministry of Internal Affairs and Communications (MIC) in cooperation with the Digital Cinema Technology Forum.

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