Reliable IP Transmission for Super Hi-Vision over Global Shared IP Networks

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Abstract We have developed a high-speed reliable IP transmission system for the live streaming of video content beyond HDTV. Secure IP Terminator is a key technology that consists of high-efficiency forward error correction, low jitter IP packet control and real-time encryption. The IP terminator offers extremely stable video transmission on shared networks constructed by multi-domain research and educational networks throughout the world. We verify system performance by transmitting coded Super Hi-Vision signals from London to Tokyo.

Keywords: LDGM-FEC, Super Hi-Vision, shared network, IP streaming

1. Introduction

High quality video and audio distribution service is one of the most promising network applications for the broadband network. The deployment of digital cinema is stimulating many advanced applications that will use higher definition imaging systems beyond HDTV. The near-term video format called "4K"⁽¹⁾ has been defined as for digital cinema with a resolution of 4Kx2K pixels. The large numbers of movie theaters with pre-installed video projectors, large screens and audio systems, significantly decreases the cost of offering special, public live views of musicals and sports games (**Fig.1**). While current live viewing events offer HD quality video, commercial 4K video devices are rapidly becoming so popular that the live streaming format is about to shift to 4K. However, even higher definition TV systems of 8Kx4K pixel video, cameras, displays and CODEC, called Super Hi-Vision (SHV)⁽²⁾ have been developed that will enable even more realistic live view services.

The cost of networks remains a steep barrier to these live view services. When 8K videos are compressed for transmission over IP networks, the bandwidth of about 300 Mbps is required even though the videos are efficiently compressed by MPEG4-AVC/H.264. Dedicated

Fig.1 Live streaming to the large venue screens.

optical fiber lines have the best quality in terms of stability during transmission, monitoring of network condition, etc. Unfortunately, dedicated lines are designed for permanent and long term use, so they are not suitable for the intermittent live view services. The most promising solution for connecting event venues is to use shared networks. Typical examples of shared networks that offer IP packet transmission rates of over 100 Mbps are the research and education (R&E) networks such as Internet2⁽³⁾. Services based on commercial shared networks are now being offered. These broadband network connections are less expensive than dedicated services.

The common problem when we use shared networks is the service quality problems caused by the relatively high packet loss rate and packet jitter. In order to resolve this problem, we have developed a high-speed reliable IP transmission system, which ensures network reliability over shared IP networks lying multiple domains. In this paper, we describe this transmission system and an experiment conducted on multi-domain global R&E networks to evaluate the feasibility of the

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Fig.2 Block diagram of reliable IP transmission system.

system. In this experiment, we transmitted coded streams of SHV videos, with the support of NHK-STRL (Science and Technology Research Labs.) in Tokyo, Japan.

2. Reliable SHV Transmission using R&E Shared Networks

Our goal of this study is to realize stable IP transmission of sub-Gbps class video signals over shared networks across the world. Next generation video applications using this class of bit-rates will play an important role in the business field. The applications include SHV distribution to end users, as well as content delivery of 2K/4K/8K for production industries.

2.1 Super Hi-Vision

Super Hi-Vision system, which is being developed by NHK, is an ultra-high-definition TV system beyond 4K. Each SHV image consists of 7,680 horizontal and 4,320 vertical pixels in the spatial domain, for a total of approximately 33 million pixels per frame. In the time domain, the frame frequency is at least 60 Hz. The basic broadcast facilities, such as cameras, displays, recorders, and CODEC systems have been developed⁴⁾. At present, the raw SHV signal is carried by the parallel connection of 16 High Definition Serial Digital Interface (HD-SDI) links; the total output of the SHV camera is 24 Gbps (16 x 1.5 Gbps). The SHV video signals are compressed by eight H.264 encoders into two MPEG2-TS signals. Total bit-rate of the MPEG2-TS stream is 280 Mbps which yields the desired video quality when projected on large venue screens.

2.2 Reliable IP Transmission System for SHV

To deliver SHV video contents over global shared IP networks such as Internet2, adequate network reliability is essential. The various disturbances expected to be encountered in the network should be canceled to maintain the video quality. Since the transport stream format demands a raw bandwidth of 280 Mbps, an IP packet

format with bandwidth of approximately 300 Mbps is needed in order to transmit SHV. The major R&E networks use 10Gbps backbone networks, but we need to take the probability of significant IP packet loss into account. In this situation, the conventional forward error correction (FEC) circuits placed in video CODECs, such as Pro-MPEG⁵⁾ are of no use. More robust FEC is required to transmit SHV videos, also, jitter compensation devices are indispensable for a stable video transmission.

3. Design and Implementation of Secure IP Terminator

To achieve secure and reliable SHV video transmission, the "secure IP transport terminator," shown in **Fig.2**, should be sited at the input and output edges of the R&E IP networks. The terminator implements three functions.

1. High-efficiency forward error correction to counter IP packet losses
2. Low jitter and synchronous IP packet control
3. Real-time encryption and decryption

We have implemented these functions as a software module running on a Linux PC system (Fedora 14); it offers programmable FEC. The PC has a single Intel Core i7-2600 CPU (3.4GHz clock, 4 cores, 8 threads) with 2 GbE Ethernet cards. The IP transport terminator has two Ethernet ports and behaves like a proxy server so that the terminator is available to all video transmission systems that use RTP/UDP protocol streams. It effectively hides packet loss and network jitter, so the IP network becomes secure and stable.

3.1 High Efficiency FEC Proof Against Large Burst Packet Loss

LDGM (Low Density Generator Matrix)⁶⁾⁷⁾ is a powerful algorithm for forward error correction that suits lossy IP networks. The IP transmission scheme discards erroneous IP packets in the networks, so the forward error

Fig.3 Forward error correction by LDGM.

Fig.4 Lightweight calculation process in LDGM decoding.

correction system based on LDPC (Low Density Parity Check) code can be simplified to LDGM; it focuses on recovering just erased packets as shown in **Fig.3**. IP packet ARQ (Automatic Repeat Request) is another way to realize reliable data transfer without redundant transmission, but in this study we focused on multicast streaming some the emphasis is placed on high throughput under the large network delays expected with international SHV video streaming. As mentioned later, burst packet losses can be quite long, sometimes more than 10,000 packets long. Since conventional error correction methods such as Reed-Solomon, which is limited to 256 blocks due to computation costs, can not handle packet losses of this length, an FEC algorithm that can work with longer blocks is indispensable. LDGM-FEC has very low computation complexity due to its sparse matrix calculation, see **Fig.4**, and it offers IP throughput potential of over 1 Gbps even when implemented in software.

3.2 Low Jitter Control and IP Stream Synchronization

The large packet arrival jitter encountered in the IP network sometimes causes TS stream PCR (Program Clock Reference) fluctuations. As shown in **Fig.5**, if the RCP jitter becomes excessive, severe decoding errors may occur. The terminator uses an IP packet sharer to

Fig.5 PCR jitter fluctuation due to the IP packet jitter.

regulate output timing. As shown in the experiment, this smoothing process is quite effective in removing packet jitter. This function successfully suppress the PCR fluctuation even when the round trip time changes significantly due to delivery route changes.

To apply the secure IP terminator for transmitting SHV, the terminator has been modified to accept 2 IP streams in parallel, the terminator in receiver output IP packets while preserving the order of the IP packers of the two streams received in the terminator in sender side. This is because the TS output of SHV encoder system consists of 2 transport streams, that should be transmitted in parallel with the accuracy of maximum of 8 mSecs difference.

3.3 Content Security

To address the issue of security for the high value contents, especially on public shared networks, encryption is indispensable for SHV transmission. Standard 128-bit AES (Advanced Encryption Standard) is selected as the encryption algorithm. The algorithm can be processed by using AES-NI functionality, which is available in the current Intel CPU series. Sustained 280Mbps processing speed is possible with hardware acceleration. The encryption protocol is based on the "Secure RTP" standard.

4. SHV Transmission Experiment on R&E Network

We evaluated the impact of the secure IP terminator on the performance achieved by the multi-domain global R&E network. This configuration represents a good example of the temporary network connections needed to support the live event services being considered for public viewing.

4.1 Connection from London to Tokyo

In the experiment, we established 2 routes on the global IP shared network environment through the sup-

Fig.6 Connection of multi-domain R&D NWs for SHV streaming.

port of R&E network organizers. **Fig.6** shows the network configuration examined. Route #1 includes JANET⁸⁾ in the UK, GEANT⁹⁾ in Europe, Internet2 in the US, and GEMnet2¹⁰⁾ in Japan. GEMnet2 (Global Enhanced Multifunctional Network) is a network test-bed of NTT Laboratories. GEMnet2 has an international line across the Pacific Ocean, and connects to Internet2 at Seattle. Internet2 connects to GEANT at Washington DC. GEANT has lines across the Atlantic Ocean and continental Europe and reaches London. BBC connects via JANET in London. These networks establish a layer 3 connection with 19 hops between BBC in London and NHK in Tokyo. At this time, we did not implement any priority controls in the network. In order to compare the characteristics of the shared network, we established route #2 that used SINET4¹¹⁾ instead of Internet2 and GEMnet2.

4.2 Measured Characteristics of the Experimental Network

During the experiment, we monitored the IP traffic in real time using the network tester SPIRENT AX/4000. Average round trip time between London and Tokyo was 275 msec. on route #1, and 249 msec. on route #2. The IP packet loss rate was about 0.07% and the maximum IP packet jitter was about 50 mSecs. on route#1. The overall delay occasionally varied by about 6 msec. due to changes in the paths set within the individual R&E networks and short burst packet losses occurred as shown in **Fig.7**.

4.3 Configuration of Experimental System

Fig.8 shows the experimental system. We transmitted coded SHV signals with the TS bit-rate of 280 Mbps from BBC labs in London to NHK STRL in Tokyo via route #1. At the terminator connected to the SHV encoder, IP streams were encrypted and redundant IP packets for LDGM-FEC were added for input to the net-

Fig.7 The fluctuations of average delay in a day.

Fig.8 Secure IP Terminator feeds TS to SHV decoder&display.

work. Even though the average IP packet loss rate was far under 1%, each burst loss was quite long and we had to select a large block size in LDGM-FEC. We set the block size parameter to 150000 and redundancy to 20%. As a result, total throughput increased to 360 Mbps. With this configuration, up to 25000 contiguous packet losses can be compensated. The average CPU load of the terminator is approximately 20%, so we did not need any special performance tuning of the PC system.

4.4 Results of SHV Transmission

Fig.9 shows the IP packet loss variation over a 12.5 hour period on a day in April 2012. The red crosses indi-

cate the number of packet loss events including parity packets, which were detected by the IP terminator at the receiver side. Near the end of the measurement period, we observed a burst packet loss of 17200 contiguous packets. However, since all packet losses were compensated by the IP terminator, there was no unrecoverable error as shown by the green crosses in Fig.9. Route #2 using SINET4 had lower packet loss rate than route #1 as shown in Fig.10. The experiment showed that dozens of IP packet loss events were fully compensated and that the SHV system operated normally most of the time. They also show, however, several loss events that the terminator could not compensate since the losses exceeded 25000 contiguous packets. In April 2012, we conducted SHV streaming for 6 days. Eliminating the loss events caused by network maintenance (made by the R&E network organizations), we found 6 excessive packet loss events over a 26 hour period in route #1, and 1 event in a 48 hour period in route#2.

When the average delay fluctuated due to changes in the path taken (see Fig.7), the flow regulation function in the secure IP terminator was able to provide adequate jitter control and thus the changes had no effect on PCR or quality of the projected SHV video.

5. Conclusion

We have developed a high-speed, reliable transmission system and have demonstrated SHV transmission over international shared IP network established on a number of backbone networks. An experiment was conducted to confirm the security and reliability of IP transport technologies implemented as software. These technologies are not specific to SHV transmission and can be more generally applied to IP transmission.

The R&E networks used in the experiment were a tough challenge for the IP terminator, and it is expected that commercial shared networks would hold the burst packet losses to much smaller values than those seen on the R&E networks. Most burst errors can be compensated, and the IP terminator is a powerful tool for future temporal networks that utilize MPLS (Multi-Protocol Label Switching) and network virtualization technology where the physical network paths are apt to change often due to automatic congestion avoidance control while preserving the logical network paths for streaming. The application layer FEC technology described herein has great potential for allowing cost effective networks to be established across the world.

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Fig.9 Measured burst packet loss in 12.5 hours.
(route #1, 2012-04-25).

Fig.10 Measured burst packet loss in 12.5 hours.
(route #2, 2012-04-19).

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