BI-DIRECTIONAL TRANSPORT AND NETWORKED DISPLAY INTERFACE OF UNCOMPRESSED HD VIDEO

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ABSTRACT

To interactively share High Definition (HD)-quality visualization over emerging ultra-high-speed network infrastructure, several lossless and low-delay real-time media (i.e., uncompressed HD video and audio) transport systems are being designed and prototyped. However, most of them still rely on expensive hardware components. As an effort to reduce the building cost of system, in this paper, we propose the integration of both transmitter and receiver machines into a single bi-directional transport system. After detailed bottleneck analysis and subsequent refinements of embedded software components, the proposed integration can provide Real-time Transport Protocol (RTP)-based bi-directional transport of uncompressed HD video and audio from a single machine. We also explain how to interface the Gbps-bandwidth display output of uncompressed HD media system to the networked tiled display of 10240 x 3200 super-high-resolution. Finally, to verify the feasibility of proposed integration, several prototype systems are built and evaluated by operating them in several different experiment scenarios.

Keywords: uncompressed HD, bi-directional transport, embedded system integration, networked tiled display.

1. INTRODUCTION

The advent of Gbps-range optical networking infrastructure and ultra-high resolution display devices are motivating ever-increasing demands toward HD (high definition)-quality sharing of video and audio among remote sites. As an answer to this demand, several uncompressed HD media transport systems – USC/ISI UltraGrid, UW/RC iHDTV, NTT i-Visto - are recently developed. UltraGrid[1] initially provides uncompressed HD video transport with more than 1.2Gbps with 720p/10bit HD video. While iHD1500, uncompressed HD version of iHDTV series, supports 1080i/10bit1080i HD video and started using cost-effective High Definition-Serial Digital Interface (HD-SDI) capture device over Windows platform. More commercially designed i-Visto can satisfy the delay-sensitive broadcasting environment and it recently expands its interfaces with studio editing systems. These uncompressed HD media transport systems, by avoiding cpu-and-time-consuming encoding/decoding processes, are capable of supporting interactive visual sharing among collaboration participants. Also, ultra-high resolution display devices, such as individual 4K display, 4K projector and distributed visualization system, enable videoconferencing with visual details and visual context. The 4K projector offers unprecedented features such as 4096 x 2160 pixel resolution (4K SXRD projector from SONY [4]) and high contrast ratio and provides dynamic viewing experience. However, these uncompressed HD transport systems as well as super-high resolution display devices are suffering the cost of expensive system buildup.

Thus, in this paper, as an effort to reduce the building cost of system, we propose the integration of both transmitter and receiver machines into a single bi-directional transport system. To do so, we need to check how to manage the high-speed data flow of uncompressed HD video and audio for bi-directionally-capable transport. So we conduct detailed bottleneck analysis and make several refinements of embedded software components to enable RTP-based bi-directional transport of uncompressed HD video and audio from a single machine. Note that, the proposed integration is made by continuing our enhancement efforts [5-8] for Linux-platform-based UltraGrid.

Also, in this paper, to reduce the cost of single ultra-high resolution display device, we suggest the use of cost-effective networked tiled display that clusters display devices together to enable ultra-high definition support. To do so, we explain how to interface the Gbps-bandwidth display output of uncompressed HD media system to the networked tiled display of 10240 x 3200 super-high-resolution. For the networked tiled display, we use so-called SMeet One Display (SMOD) networked display system[1] [9], which is being developed at GIST to visualize various types of media by clustering

[1] SMOD is realized after Scalable Adaptive Graphics Environment (SAGE) [10], which plays the role of display middleware to visualize any kind of pixel-stream to a tiled display.

heterogeneous display tiles (i.e., devices) into one virtual display. SMOD comprises of three tightly-networked components such as clustered display devices, display controller (as part of display manager), and display gateway. With networked tiled display, each display device receives (via Gbps-speed networking) raw (RGB or YUV) display data directly from the uncompressed HD media system. It then visualizes received HD video while following the synchronized coordination of display controller. The display manager manages the whole SMOD system, handles user display interactions (such as move and resize), and performs the synchronization of all display devices via the display controller.

Finally, to verify the feasibility of proposed integration, several prototype systems are built and evaluated by operating them in several different experiment scenarios. Especially, by focusing on the system/network-side configuration for bi-directional transport, we demonstrate HD video transport over light-path-provisioned network connections. The remainder of this paper is organized as follows. In Section 2, after introducing the target uncompressed HD media transport system, hardware and software-side analysis are explained to support bi-directional transport from a single machine. Integration and verification tests are presented in Section 3. After showing the experimental evaluation results in Section 4, we wrap up this paper in Section 5.

2. UNCOMPRESSED HD SYSTEM FOR BI-DIRECTIONAL TRANSPORT

2.1 System Overview

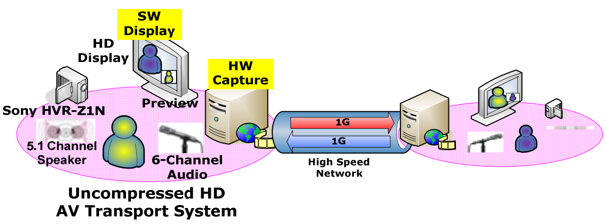

Fig. 1: Bi-directional transport system for uncompressed HD media.

To support an interactive video-based collaboration environment with ultimate HD video quality, the uncompressed HD video transport system has been used. The uncompressed version of HD (commonly referred as HDTV) video requires around 1.5 Gbps and thus it is really challenging to transport this huge-size uncompressed HD video contents in real-time. Especially, since the time-consuming encoding/decoding processes are eliminated, it provides the best interactive HD video-based communication with ultra-high quality and low-latency visualization.

However, the uncompressed HD media systems are demanding several challenges. The proposed realization is attempting to build more flexible and cost-effective uncompressed HD video system. Still there have been a number of remaining problems with the required system integration, especially with the Linux platform. The cost of existing systems has been too expensive because it requires high-performance media and networking interface components.

The criterion of uncompressed HD media transport system is hardware-based capture and software-based display in Fig. 1. The system for uncompressed HD media transport consists of hardware-based audio/video capture, high-speed transport, and hardware/software-based display. It performs with HD-SDI and display performs with xVideo (XV) and Simple DirectMedia Layer (SDL) library based display module.

2.2 HW-based Bi-directional Transport System

In this section, we present analysis for bi-directional transport regarding hardware specification and system integration.

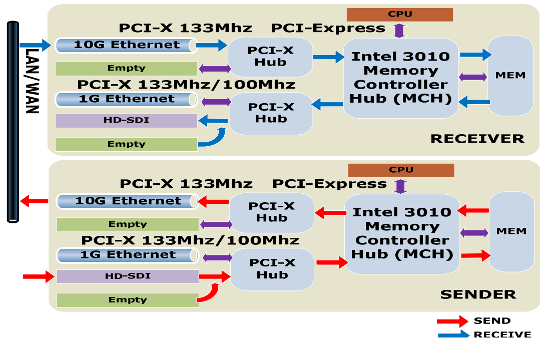

Fig. 2: Motherboard performance flows [7].

The hardware-based capture is explained in Fig. 2. Note that because one HD-SDI interface for uncompressed HD media requires 1.5Gbps, we need either single 10Gbps or dual 1Gbps Network Interface Cards (NIC). In fact, the proposed system consists of two 133MHz Peripheral Component Interconnect Extension (PCI-X) slot and two 100MHz PCI-X slot. Theoretical maximum speed of 64 bit slots can support 1GBytes/s with 133MHz bus [7]. Memory Control Hub (MCH) manages data flows among CPU interface, DDR2 system memory interface, Peripheral Component Interconnect (PCI) express interface, Direct Media interface optimized by the CPU. The captured media data is sent by using 133 MHz PCI-X hub, MCH, and HD-SDI interface over 10Gbps high-speed network. Also, the proposed system uses CPU core2quad. The four independent processor cores are accumulated to one physical package and operate at the identical frequency. It shortens the processing and executing time with prediction mechanism. In addition, it provides the cache performance and highly efficient subordinate system. When the CPU of system processes SSE/SSE2/SSE3 (streaming SIMD extensions) of unit size, it can increase software performance with graphic, video, and audio.

Approaching real-time performance usually requires taking advantage of special hardware. Especially, existing uncompressed HD transport systems are typically using two machines to support sending and receiving. Thus, in this paper, to attain cost-effectiveness, we attempt to realize bi-directional transport support with a single machine. In the followings, we list several aspects to be considered in terms of hardware performance. For instance, PCI slot should support high-speed data transport (i.e., more than 100 MHz) to manage real-time and bulky bi-directional traffic. It would be good to generalize the video capture interface to cover real-time streaming. Therefore, the PCI slot performance of machine should manage a HD-SDI interface without any internal bottleneck. In fact, resource consuming repeated operations (e.g., memory copy) limit the number of supported streams from the server. Memory-copy operation involves static allocation of necessary buffers and creates corresponding overhead. Thus, the support of zero-copy operation is highly useful.

Next, to exploit hardware overload from bulky traffic, using multiple NICs is a cost-effective method. In fact, the proposed system for bi-directional transport takes advantage of dual-port transmission, which binds two Gigabit NICs to support transmission rate over 1 Gbps. To process massive data in/out, NICs have to be spitted to transmit at the same time.

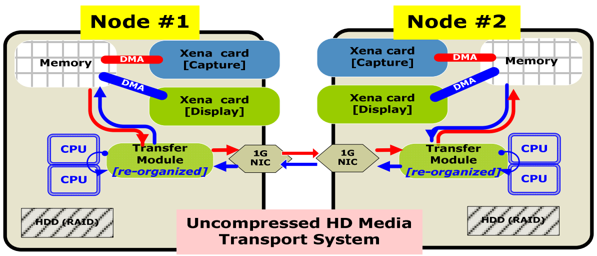

Fig. 3: Hardware-based bi-directional transport.

In hardware-based configuration depicted in Fig. 3, we alternate system configuration by using two HD-SDI interfaces for capture and display in single machine. Note that, when one HD-SDI interface is operated, either capture or display module can be loaded. Thus, we suggest the use of two HD-SDI interfaces in a machine with sharing memory.

2.3 Software-based Preview Video for Effective Bi-directional Transport

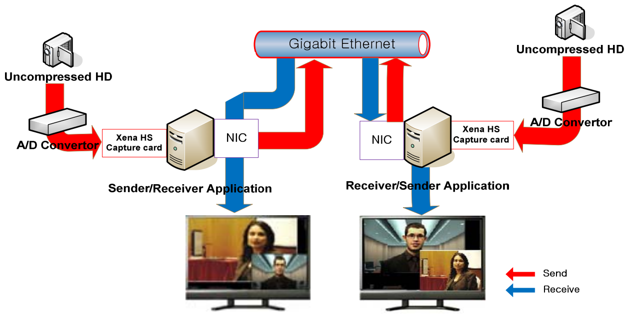

Fig. 4: Software-based preview video.

If we want to avoid the use of two HD-SDI capture cards, we can replace hardware-based display with software-based (i.e., graphics-card-assisted) display. Thus, bi-directional transport is also realized in software-based display configuration to make a flexible HD system. Additional merit of this configuration is that we can add real-time preview function. Without the real-time preview of sending video, the uncompressed HD media transport system has trouble to setting up suitable view. In fact, the real-time preview function can help users adjust settings by monitoring the sending view.

Thus, we add the real-time preview of sender side as shown in Fig. 4. To do so, it is required to add a forwarding frame module to display the sender view. A distributed module of video frame is added right after a frame grabber. In that case, it is required to consider having an effect on transmitting packets. To avoid mutual interference between preview and transmitting traffics, the preview frame is sent right after the end of a transmitting frame. The acquired frame from a HD video camera is stored to frame buffer via the HD-SDI interface. The distributed module delivers captured frames to be presented with SDL (simple directmedia layer) Application Programming Interface (API) on sender's monitor.

4. INTERFACING WITH NETWORKED TILED DISPLAY

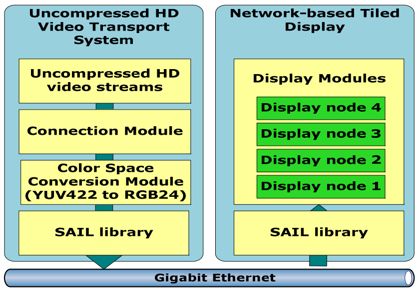

Fig. 5: Interfacing with networked tiled display.

To support scalable visualization over networked tiled display, as shown in Fig. 5, we have developed an interface module for SMOD as well as SAGE. The uncompressed HD video system should deliver HD video stream (1920 x 1080 x 8 bit pixels @ 29.97 fps, YUV 4:2:2) to the tiles of networked displays, where the whole bandwidth ranges up to 1 Gbps. That is, it captures/receives the HD stream and transmits/forwards color-converted pieces to all corresponding tiles of networked displays.

Regarding color-space conversion, there are multiple choices depending on the supported set of color coordinates with the software for networked tiled display. For example, if the networked display only supports RGB color formats (RGB16, RGB24 and RGB32), the input YUV color video should be converted and typically the conversion from YUV422 to RGB24 is commonly used. However, still, whether we will perform the color conversion before or after delivering the HD stream to the networked tiled display is not fixed. Actually this choice is partially related to the tradeoff of transport overhead and processing burden. Thus, after conducting several tests, we are currently realized it by converting the stream before transport. However, please note that this is really subject to the network and device configuration of underlying networked tiled display system.

Also, it should be noted that special attention to the size of buffers is required. Normally it is necessary to set the sizes of the reception and transmission buffers to match that of one full frame of video. Also the maximum packet size is affecting the performance. When 1500byte Maximum Transfer Unit (MTU) is used, the system can manage to deliver the HD stream to the networked tiled display with difficulty. If we can support the jumbo-frame (i.e., 9000 byte MTU) packets, the system is working with flexible processing margin.

Another issue with interfacing networked tiled display is that currently realized software for networked tiled display is adopting TCP for its transport. Thus, it is possible to attempt performance enhancement by applying TCP tuning or changing TCP stacks. Thus, in this paper, we tested with Binary Increase Congestion control (BIC) and CUBIC (extended version of BIC) versions of TCP, which are known to be good for heavy traffics. First, we propose several TCP tuning schemes, such as increasing TCP transport window size for no acknowledge (NACK), allocating large enough socket buffers, and reconfiguring TCP segment sizes to use maximum MTU packet by using a path MTU discovery function. Second, we suggest the use of CUBIC version of TCP. In fact, the lower versions of TCP (until Linux kernel 2.6.8) cause trouble in the form of long delays over high-speed networks. However, with the new version of Linux kernel (since version 2.6.9), CUBIC TCP is adopted. CUBIC TCP can reduce delay over high-speed network environments and improve its TCP-friendliness and RTT-fairness [11].

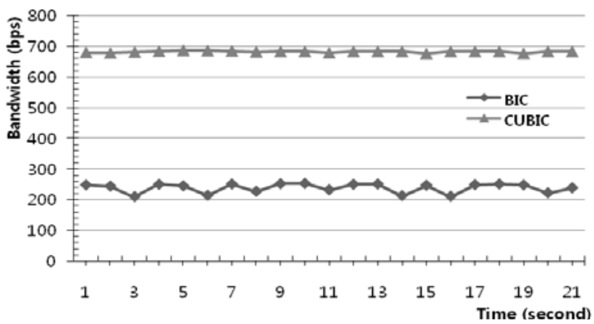

Fig. 6: Network performance through system tuning.

Fig. 6 apparently shows the effect of employed TCP version to the networked display performance (i.e., between uncompressed HD receiver and networked tiled display). The average bandwidth is improved from 239.4 Mbps to 682.1 Mbps, which also implies reduced packet losses with CUBIC TCP.

4. EXPERIMENT RESULTS

In this section, we present several experimental results regarding the networking and system performance of bi-directional HD video transport system and its interface with networked tiled display. For the experimental evaluation, we have tested the performance in two setup environments: 1) hardware-based real-time capture/display setup between Gwangju (GIST) and Daejeon (KISTI); 2) software-based real-time capture/display setup over internal LAN. Also, we mainly conduct the experiment with 8bit uncompressed HD video and 24bit 48 KHz audio streams, where the evaluation is lasted for 20 ~ 60 minutes.

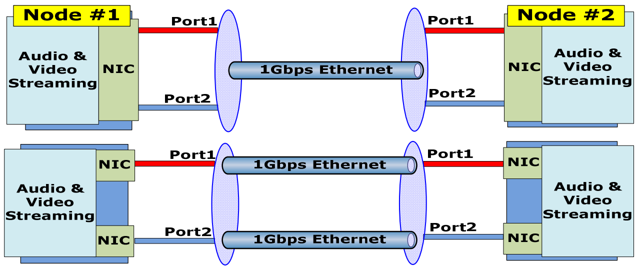

Fig. 7: Single 1GbE (Experiment #1-1, top) and dual 1GbE (Experiment #1-2, bottom) configurations.

In the top of Fig. 7, Experiment #1-1 shows the configuration for bi-directional transport with single 1GbE NIC, where two processes at Node #1 and Node #2 share a single 1Gbps network path. In this case, it is required to configure different port numbers to separate sending and receiving of audio/video streams. In comparison, Experiment #1-2 (at the bottom of Fig. 7) shows the case of dual 1GbE adaptors, where both eth0 and eth1 are required to configure 9180-size jumbo frame (with 9000 txqueuelen as well).

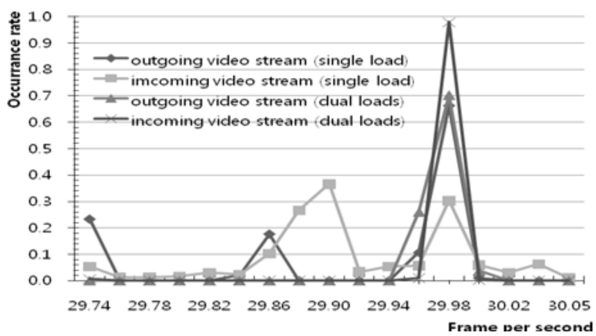

Fig. 8: Frame per second.

Fig. 8 indicates the change of video frame rate that compares single and dual network (load) paths. It is experimentally observed that in case of single path, 61.5% of frame rates maintain at 29.97 fps. At the receiving side, the frames are somewhat time-varied (0.39% loss rate). With dual paths, 97.3% of frame rates retain at 29.97 fps. The receiving side witnesses an outstanding playout rate of 99.3% (no loss rate). Like this, Experiment #1-2 shows improved and stabilized performance than Experiment #1-1.

Fig. 9 illustrates the snapshots of various network-based experiments that are carried with the proposed HD transport system with bi-directional support. First, on the top of Fig. 9, the artistic dance performance is delivered in live to international destinations (e.g., Canada, Netherland, and Spain) by using hardware-based playout mode. In this case, we configure dual HD-SDI interfaces to cover both capture and display. Second, in the middle of Fig. 9, we show the interactive video conferencing scenario with preview HD videos, where participants can adjust the preview setup on the monitor. Third, in the bottom of Fig. 9, the interface with networked tiled display is depicted. With the tiling, we can support ultra-high-resolution and, with appropriate control of frame rate, we can adjust the delivery to avoid video quality deterioration due to packet loss.

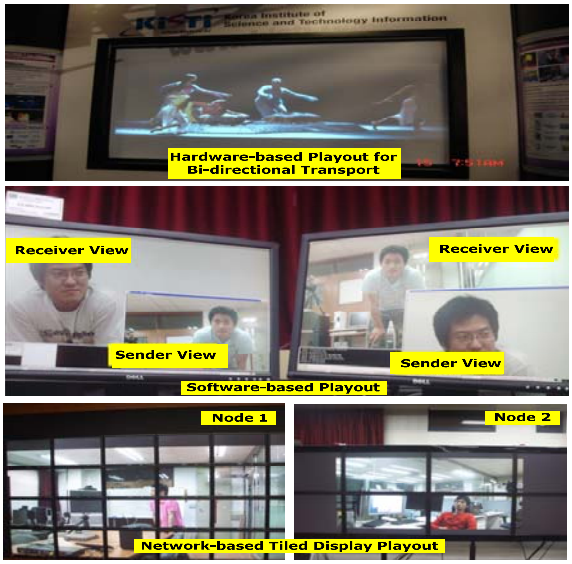

Fig. 9: Experimental snapshots of several Bi-directional transport scenarios.

5. CONCLUSION

In this paper, bi-directional transport system for uncompressed HD video transport system is introduced to address requirements for networked multimedia application. Together with networked tiled display, the proposed system can make immersive playout and real-time interactivity. However, the proposed system still requires further refinements: optimizing memory usage for software-based bi-directional transport, diversifying the choice of HD video capture (i.e., HDMI support), and minimizing the latency of system down to 100 ms.

ACKNOWLEDGEMENT

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