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Organization: University of Washington
Delivery Selection: HDTV over Internet Protocol
Driving Applications: Public Relations and Fundraising Event
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Live High Definition (HD) Video Feed From Rome & Beijing Over an IP Network

Introduction

On October 15, 2004, the University of Washington hosted *Come Together Washington*, a celebration of community and University achievements. Over 7,000 people attended the celebration on the UW campus in the Bank of America Arena Hec Edmundson Pavilion to hear the keynote address by Microsoft founder Bill Gates.

In addition the evening's emcee, Professor Hubert Locke, Dean Emeritus - Evans School, interacted with UW students and faculty in Beijing and in Rome through a High Definition Television feed streaming over the Internet. This interaction was the high point of the evening. Spontaneous applause erupted from the crowd as the first images appeared on two large screens in the Pavilion, and everyone realized that what they were seeing had never been done before.

University production, networking and streaming engineers, using technology developed and pioneered at UW, along with their technology and networking partners, staged the first live, High Definition Television (HDTV) stream using Internet Protocol (IP) simultaneously from Beijing and Rome to Seattle, Washington.

Appreciation of the significance of this event requires a brief history of the UW's work with streaming HDTV.

Early Stages and First Steps

The University of Washington has long been associated with Internet HDTV and pioneered many of the techniques and software used for this event. Early in 1999 we began looking for ways to transmit HDTV over the high-capacity Internet2 "Abilene" network. With generous support from Sony Electronics, these efforts culminated in a successful demonstration at the Fall 1999 Internet2 members' meeting in Seattle, where two HDTV streams were simultaneously sent from Stanford University to the University of Washington.

Building on the success of the Internet2 meeting, the next challenge was to send five concurrent 270Mbps HDTV streams over IP. The Supercomputing '99 conference provided the venue for this ambitious demonstration. Standard broadcast industry data rates and compression schemes

formed the foundation of the demonstration. Commercially available equipment was used to originate and display the HD video streams, while UW engineers combined specialized video hardware and high-performance personal computers with original software to take standard HD streams and convert them to Internet datagrams.

The demonstration also featured four other streaming signals using HDTV video servers developed at UW. Video servers had previously recorded HDCAM-rate video. During the demonstration, the video servers accessed the data from a disk, converted video frames to data packets and then transmitted them over the network.

All five of the workstations used in the demonstration were connected to high-speed Gigabit Ethernet ports on the UW network, which in turn was attached to the Pacific/Northwest Gigapop in downtown Seattle via an OC-48c SONET connection (2.5Gbps). From Seattle, the data traversed another OC-48c SONET connection to a Gigapop router located on the SC99 Exhibit floor in Portland. The path included routers and switches from several vendors including Juniper Networks, Foundry Networks, and Cisco Systems.

In Portland, packets were received by another five custom-configured PC workstations. After handling error correction and retransmit requests, video data was passed out the 270Mbps SDTI interface to an external Sony HDCAM decoder. The output from the HDCAM decoder was then applied to an HDTV plasma display.

Professor Locke speaking - Hec Edmunson Pavilion

The Convergence of Broadcast and the Internet

A cross-country five-stream demonstration at NAB2000 pushed the boundaries of research networks one step further. The convergence of Broadcast and the Internet was demonstrated in Las Vegas when multiple live and pre-recorded HD streams from KING5 Television in Seattle were streamed to the convention, decoded and then fed into Sony's HD-Switcher. A director and a technical director switched the five signals live on the show floor and streamed the switched signal back to Seattle to be broadcast directly to air from the IP network stream.

Since those early HDTV over IP demonstrations, UW engineers worked to improve the process. In 2001 a live UW HDTV signal was sent over the Internet to Amsterdam. In 2002 the UW conducted a live demonstration from Korea; in 2004 we demonstrated a live 2-way interactive HDTV videoconference between Seattle and Australia. UW has also been active in pioneering HDTV to a desktop PC encoded at 1920x1080 (1080i) and 1280x720 (720p) resolution for playback at 19.2mbps and 5mbps respectively.

(For more information on the HDTV over IP projects at UW and the ResearchChannel, please visit our Website at http://www.researchchannel.org/projects/.)

In Spring 2004, UW approached the Computing & Communications Department and UWTV to help kick off the University's Capital fundraising campaign *Come Together Washington*, a celebration of the contributions our community and UW make to society and the world.

The organizers wanted to show that UW had both local roots and a global reach. University researchers and students work and study around the world; including them in the celebration was an important goal. This was an opportunity to help UW and put to practical use what up until then had only been used in demonstrations.

Standard television satellite technology, used since the mid-1960s, was the most reliable and obvious choice. By using this technology we could rent satellite up-link equipment anywhere in Europe and most of Asia and beam a live Standard Definition Television (SDTV) signal to Seattle.

However, we knew that HDTV would have the greatest impact on the 7,000 people expected to attend the event. Having students in Rome or China speak directly to the audience in Seattle with the clarity, detail and presence of live interactive HDTV would tell a stronger story than the usual pre-taped video or SDTV feed. It would also serve as a demonstration of the HDTV-IP technology.

Selection of Participating Locations

The first challenge was to choose the remote locations. The University wanted its students at the University's Rome Center and its program at Sichuan University in Chengdu, China to participate in the telecast. While the Internet is accessible from most locations in the world with telephone access, a good high-speed DSL connection typically streams only 250Kbps; a standard dial-up connection handles a slim 58Kbps.

In addition, we needed a route from the remote locations to Seattle that traveled only on high bandwidth pathways. Clearly, our plans to transmit an HDTV stream over IP at 270Mbps were

restricted both by the amount of bandwidth available at these remote locations and by the lack of high speed routes.
UW engineers had been experimenting with a Harmonic encoder whose original purpose was to encode HD video for a server. The engineers used it to compress HD video into a 19.8Mbps stream, as finding a pathway to carry a 19.8Mbps stream would be easier than finding one to carry a 270Mbps stream.

The engineers researched broadband networks across the Pacific and Europe. Even though the HD video was streamed at 19.8Mbps, other Internet traffic on the networks required that we use a broadband Internet path that could handle at least 30Mbps. By mid-summer we had identified and tested 30Mbps pathways to both Rome and Beijing.

For high bandwidth network access to Rome we partnered with Gruppo Armonizzazione Reti di Ricerca or GARR, the Italian Academic and Research Network. While this solved the issue of transmitting the telecast to Rome, the students and faculty in Rome wanted to originate their HD broadcast from the UW Rome Center in The Palazzo Pio. Even a temporary fiber optic connection to the Palazzo Pio would be very costly and take several months to install.

Fortunately the GARR network originated just a few miles from the UW Rome Center in the offices of CASPUR, an Italian universities and research consortium for super-computing. CASPUR generously donated access to the GARR network, space to set up our cameras and encoders, and technical support.

China was more difficult. UW's partner program at Chengdu's Sichuan University was located several hundred miles from Beijing. As it was decided that it would be easier to bring the students and faculty from Chengdu to Beijing, the China Education and Research Network, or CERNET, graciously assisted by providing their videoconferencing studio, network connectivity and technical support.

Project Challenges: From Limited Bandwidth to International Customs

With UW community-based programs throughout the State of Washington, we were asked to provide a live feed from the Yakama Nation, 150 miles from UW. While high bandwidth pathways and hubs enabled us to connect to Beijing, we were unable to link to a site across our state. We resorted to the installation of five T-1 lines to accommodate a 5.6Mbps Standard Definition video stream.

Redundancy was necessary to ensure a successful telecast. As our engineer conducted on-site tests in Beijing and Rome, a videographer interviewed faculty and students and produced a short video to screen in the event that the network failed.

As preparations continued, other issues came to light. Overseas production requires a substantial amount of customs paperwork, declaring and accounting for every piece of equipment. This went smoothly for our set-up in Rome; however, we encountered more difficulty in China. Chinese Customs seized our HD camera and forced the crew to make alternate arrangements.

With cameras set up in Rome and Beijing, a test HD video signal was encoded through the Harmonic encoder to a 19.8Mbps stream, which was then sent to a Path 1 Ax100 IP Video Gateway designed for transporting real-time broadcast-quality digital video over IP networks. The set-up worked exceptionally well and the test was successful.

Once the IP stream arrived in Seattle it was routed through another Path 1 Ax100 IP Video Gateway, decoded and reconverted by the Harmonic decoder into a 1080i HD signal. Special fiber optic lines were installed to make the final run from our studios to the Pavilion.

Local Display & Production

Project plans now called for routing to the two large HD projection screens and two auxiliary SD projection screens, two live HD signals from the floor of the Pavilion, two live HD signals from Rome and Beijing, a SD signal from the Yakama Nation and, for back up, two redundant SD signals from Rome and Beijing and pre-recorded back up HD videotapes for playback from the truck, if necessary.

The program also included HD graphics for program transitions and SD graphics for the auxiliary screens. All of these sources were synced and switched for the large screens.

HD Production Truck – Control Center

As UW lacked sufficient equipment to stage this event, we rented an HD production truck with all necessary equipment and an experienced and professional crew. A local multimedia producer was commissioned to produce an opening montage of historical photographs that played on the four large screens as the live audience in Seattle entered the auditorium. The multimedia show was converted to HD video, looped and synced to play on cue.

A delay in the processing of the live HD image presented a further challenge. Transporting HD video at 19.8Mbps over IP added no signal delay, but encoding and decoding the signals inserted

a delay of about four seconds. A highly skilled audio technician opening and closing microphones at strategic times prevented any echo caused by the delay.
Inside the HD truck just outside the Pavilion, the program's director, Christine Ruiz with technical director, Derek Hay were connected by headphones with the two camera operators and the director and technicians for the live show.

Ms. Ruiz was also connected to the engineers monitoring the HD IP streams as they were decoded. She was also connected via phone lines to our engineers in Yakima, Beijing, and Rome. Except for the HD streams coming over IP, this setup would be familiar to anyone involved in a multiple-satellite live production.

HD Live from Seattle, Rome & Beijing

As the scheduled broadcast time approached, more then 7,000 supporters and friends of UW filled the Pavilion bleachers. Music rose, lights dimmed, and a spotlight illuminated the stage and the emcee, Professor Hubert Locke, made his entrance. Behind Professor Locke sat 40 students. Suspended on either side of the stage were four large screens, two of them projecting an HD image of Professor Locke, the other two displaying titles and graphics.

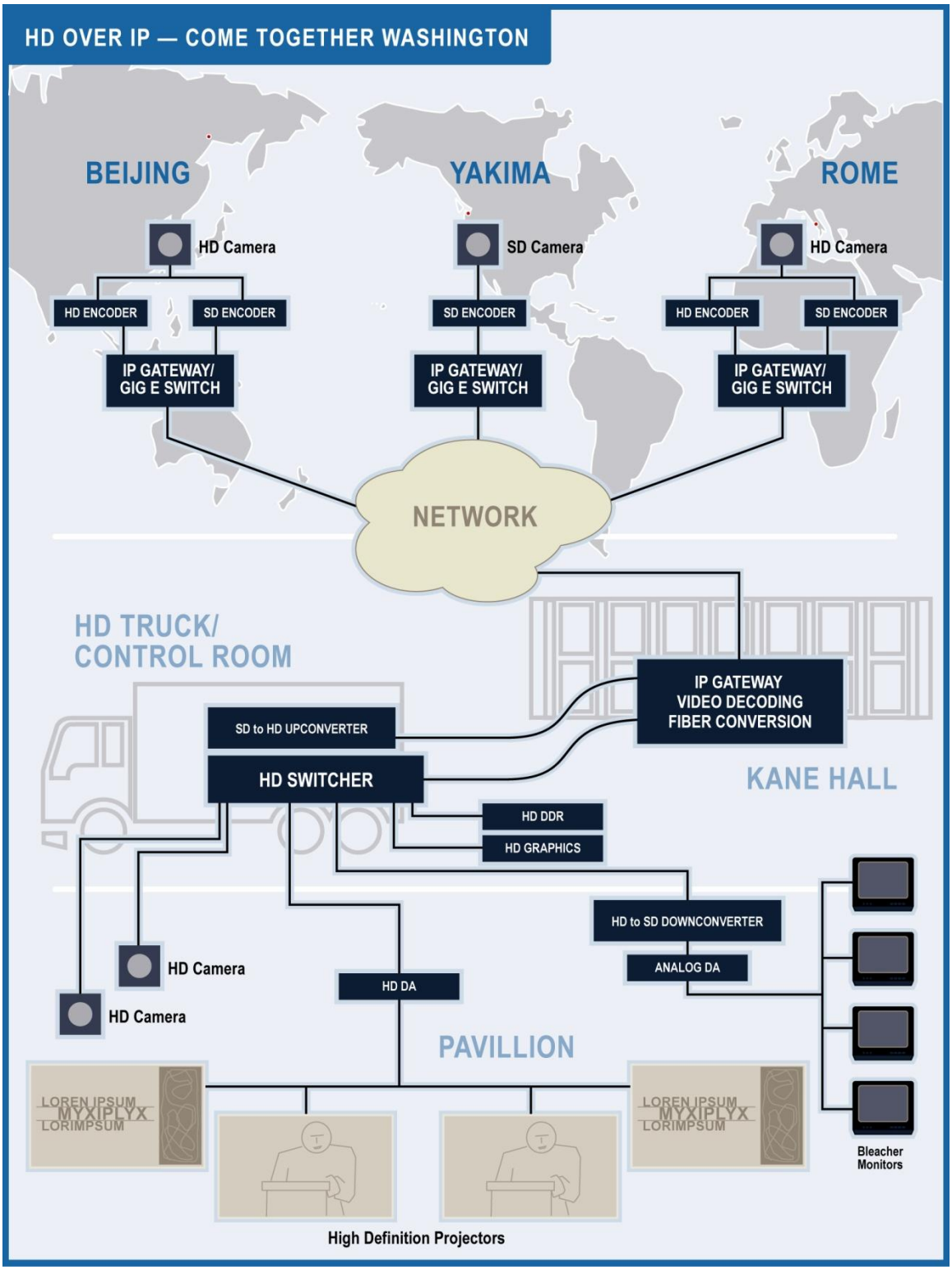
At two in the morning in Rome and mid-morning in Beijing, everyone was ready and alert. Across the Cascade Mountains, a Yakama Nation gathering of business students, faculty and local business people sat ready to tell the global audience about the positive effects of the University on their lives.

Professor Locke announced the Internet feed from Beijing. HDTV is still a rare sight for most people and the quality of video on the Internet is generally poor. As Professor Locke welcomed the larger than life, crystal clear image of a small group of students and their professors in the CERNET offices in Beijing there was an audible gasp from the audience and a round of applause. The immediacy and clarity of the Beijing students made them a part of the event. Professor Locke and the students conversed for a few moments before turning to the keynote speaker for the evening, Bill Gates.

Twenty minutes later, the students in Rome met the with the same positive audience response. The evening's only flaw occurred when an audio plug failed in the master control room, aborting the SD feed. The problem was resolved so quickly that what seemed a large failure was only a small blip in the program for the audience.

The presentation was a great success. For the first time HDTV signals were encoded and streamed over the Internet at 19.8Mbps from two separate continents to North America and switched for a live event. To many, this would seem unnecessary as satellite technology would have accomplished the same thing with less effort.

However, our event illustrated the advantages of HDTV over IP. They include the ability to leverage the network infrastructure already in place to transport the HD signals, unrestricted access to the signal, broadcast quality HDTV, and the freedom to locate wherever there is a high bandwidth connection.


HD OVER IP — COME TOGETHER WASHINGTON
BEIJING
YAKIMA
ROME
HD Camera
SD Camera
HD Camera
HD ENCODER
SD ENCODER
SD ENCODER
HD ENCODER
SD ENCODER
IP GATEWAY/ GIG E SWITCH
IP GATEWAY/ GIG E SWITCH
IP GATEWAY/ GIG E SWITCH
NETWORK
HD TRUCK/ CONTROL ROOM
IP GATEWAY VIDEO DECODING FIBER CONVERSION
SD to HD UPCONVERTER
HD SWITCHER
KANE HALL
HD DDR
HD GRAPHICS
HD to SD DOWNCONVERTER
ANALOG DA
HD Camera
HD Camera
HD DA
PAVILLION
LOREN IPSUM MYXIPLYX LORIMPSUM
LOREN IPSUM MYXIPLYX LORIMPSUM
Bleacher Monitors
High Definition Projectors

Conclusion

The intimacy and clarity of a live HDTV image has an immediate impact on an audience. The possibilities of using this technology are evident wherever image quality or a personal connection with the viewer is critical.

For example, live interactive HDTV over IP videoconferencing will be more effective, as will live images projected to large audiences from remote locations. Other applications include interactive collaboration such as live surgery, theatrical films projected in theatres without film, HDTV on-demand to the home television or computer, live HD productions with cameras on different continents from the director and the audience.

The obstacles to HDTV over IP are quickly falling as the high bandwidth Internet infrastructure is built up, the cost of HDTV encoders/decoders comes down, the processing speed of the HDTV encoders/decoders increases and HDTV usage expands.

For a detailed description of the *Come Together Washington* event and other HDTV Internet demonstrations, visit the University of Washington's Internet HDTV Web site at http://www.washington.edu/hdtv/.