A question I’m frequently asked is, “What’s the killer app for Internet2?” People want to know if there is an application that will change our use of the Internet the way VisiCalc led to the wide use of electronic spreadsheets or the way the Mosaic browser catalyzed access to the Web. Although planning or anticipating new technological products is extremely difficult, I do believe that digital video—in some form—will play a major role in applications that will change how we teach, learn, collaborate, and conduct research in higher education.
Internet2 networks are like a time machine, anticipating what may be possible in the future.

So, how are colleges and universities using digital video today? Specifically, what is possible across Internet2 high-performance networks? A consortium of 185 universities (over 100 corporate, government, and non-profit organizations, Internet2 (<http://www.internet2.edu/>)) is working to build and deploy advanced research and education applications on an enhanced networking infrastructure. Internet2 networks are like a time machine, anticipating what may be possible in the future when everyone has access to high-speed broadband connections at home, school, and work.

The Situation Today

Why are so many people using digital video on a daily basis? First, the equipment is getting cheaper. This includes everything from the cameras used to capture the images to the servers used to deliver the video across the network. In addition, the hardware and software are getting easier to use. In case of ease of use, tools such as Apple’s iMovie are bringing video editing closer and closer to word processing.

Video quality is also improving. We no longer have to be satisfied with postage-stamp sized images that get smaller and change once or twice per second. We can deliver full-screen, full-motion video. This comes from innovations in compression techniques, faster personal computers, and faster networks.

We’re also learning. The early adopters of digital video technology are sharing their lessons learned: ViDe, the video development research consortium based within SURA (the SouthEastern Universities Research Association), has developed a widely referenced video “cookbook” documenting members’ experiences and recommendations (<http://www.vide.net/>).

Finally, standards are maturing. It is straightforward today, for example, to purchase videoconferencing equipment based on the international H.323 standards from one vendor and have it interoperate across the Internet with a different vendor’s equipment. However, despite the increasing availability of standards-based solutions, we aren’t narrowing in on a single approach to using digital video. An institution will face multiple choices when seeking a solution to its digital video needs.

Uses for Digital Video

Digital videos have myriad uses. Two main categories are videoconferencing and streaming video. Videoconferencing can be delivered to one viewer or to multiple viewers simultaneously. Streaming video—which can be live, scheduled, or on-demand—can also be delivered either one-to-one or to multiple viewers. The following list provides examples of how colleges and universities are implementing both streaming video and videoconferencing:

- The University of Oklahoma has been very active in digital video through its School of Music. It has partnered with other institutions on master music classes and has participated in several Internet file inclusive of the Virtual Halloween Concert held in October 2000. The New World Symphony, which also participated in the Halloween Concert, joined Internet2 specifically for the opportunity to provide remote master classes, auditions, and other collaborations.

- The Megaconference is a large H.323-based videoconferencing effort (<http://www.mega-net.net/megaconference/>). Led by Bob Dixon of Ohio State University and with participation by scores of institutions, two major Megaconference events were held at Internet2 member meetings in 1999 and 2000. Megaconference II offered thirteen remote presentations, with approximately one hundred observing sites, and included participation from Antarctica.

- There are exciting innovations in remote instrument observation and control. The University of North Carolina at Chapel Hill developed the NanoManipulator (<http://www.cs.unc.edu/Research/irio/>). This application allows long-distance remote control of a scanning-probe microscope; the viewer observes objects at nanometer scale as three-dimensional images. A haptic, or force-feedback device, allows the viewer to “touch” what he or she sees.

- Streaming video efforts include the ResearchChannel consortium, led by the University of Washington (<http://www.researchchannel.com/>). The ResearchChannel provides live and on-demand video of university-developed content. The ResearchChannel has also undertaken several experiments with high-definition television across advanced processing environments.

- The International Center for Advanced Internet Research (iCAIR) at Northwestern University has a video portfolio of digital video projects (<http://www.icair.org/>). A newly launched initiative provides access to live and archival footage from C-SPAN at higher quality than is available from C-SPAN’s commercial Internet link.

- The Visual History Foundation (<http://www.vhf.org>) is working to see if its collection of more than 50,000 interviews of Holocaust survivors can be made available over Internet2 networks. Digitized as approximately 250,000 hours of MPEG-1 video and stored on a network-accessible server, the Visual History Foundation’s collection could serve as an important resource for tolerance education.

- Several university-owned public television stations are experimenting with a prototype work-flow environment that allows station programmers to preview shows, evaluate promotional clips and other materials, and book the broadcasts. Although home viewing is still achieved most efficiently using a combination of satellite and antenna delivery, this new environment might evolve to offer networked-based alternatives to the primary over-the-air scheduled shows.

- Internet-based video-editing environments are emerging. Videos is a project of the University of Oxford Zoology Department. Dr. Edward S. Shotton, a biologist, wanted an easy way to edit time-lapse microscope videos. He wanted to be able to select certain portions of a video file (in/out cuts) and also to crop the image. This prototype effort is evolving toward wide use through a joint project of UKERNA, the United Kingdom’s advanced networking organization, and Internet2.

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The Access Grid provides a new mode for formal and informal international collaboration between institutions.

and are often installed in conference rooms and classrooms. Increasingly popular are USB-based units that attach to a laptop or workstation and use the computer display for the video images. Ranging in price from $500 to $1,000, these lack some of the functionality of the stand-alone units, but the video and audio quality is good and the portability can be quite useful. Multipoint control units range in price from about $15,000 to $100,000 or more, depending on how many simultaneous users are supported. Popular H.323 hardware vendors include Polycom, VCON, PictureTel, and Radvision. Microsoft provides the software H.323 product NetMeeting.

The "MBone-tools" are a collection of video and audio applications that use Internet protocol multicast to share content with a wide number of participants. The video uses the same encoder as the H.323 standards, generating approximately 400 Kbps of data traffic. One MBone implementation example is the Virtual Rooms Videoconferencing System (VRVS) from the California Institute of Technology and CERN, the European particle physics laboratory (http://www.vrvs.org/). With the objective of supporting collaborations within the global high-energy physics community, VRVS has deployed reflectors that allow participation by non-multicast-enabled sites. In addition, the VRVS team has developed gateways that allow participation from non-MBone tools such as H.323, QuickTime, and MPEG-2. Most of the software used by the MBone-based environments is freely available. The costs of cameras and encoders depend on the desired quality but start at around $100, going up to perhaps several hundred dollars.

The Access Grid (http://www.accessgrid.org/) provides a new mode for formal and informal international collaboration between institutions. An Access Grid-enabled room contains video cameras covering several different angles and providing close and wide shots of the space. Three wall-sized projected screens can show dozens of full-motion video images from remote sites along with presentation materials (e.g., PowerPoint slides). Audio is enabled through microphones and speakers around the room. Based on the Mbone tools, the Access Grid relies on network multicast and can put serious stress on campus routers. Even a modest-scale Access Grid event can generate over 20 Mbps of multicast traffic, which could overload most routers deployed today. Access Grid nodes are typically run twenty-four hours per day to facilitate ad hoc use. An Access Grid node, serving one room, consists of four personal computers running Linux and Windows, three to four cameras, three projectors, microphones, and an echo-cancellation device. Access Grid nodes cannot be bought but must be built based on plans from Argonne National Laboratory. The total hardware cost is approximately $40,000 to $50,000.

Access Grids also require significant system administrator time, since the software changes fairly frequently. Successful Access Grid uses include "drop-in" environments for distributed colleague interaction, training programs, and conference presentations and attendance.

MPEG (Moving Picture Experts Group) is a family of standards for encoding audio and video. MPEG-1 is somewhat inferior to VCR-quality video images, whereas MPEG-2 is typically described as being broadcast quality. MPEG-1 data rates are typically 1.5 to 3 Mbps. MPEG-2 data rates range from 3 to 32 Mbps. MPEG-2 based videoconferencing—only for MPEG-2 streaming. Popular MPEG-2 vendors include Optrevision, Optibase, Minerva, and Cisco (via its PiStream line). MPEG-4 is a new standard providing a wide range of quality and data transfer rates. Its initial commercial focus is video-on-demand streaming at a quality higher than that of MPEG-1 but at only 300–400 Kbps.

When using these videoconferencing technologies, higher education institutions need to consider several issues:

- Production salaries. As the quality of the video image improves, production values become more important. For example, lighting and camera quality are not as critical with H.323 and the MBone tools as they are with MPEG-2-based videoconferencing.
- Low delay. High-bandwidth networks can transport high-quality video images. To squeeze digital video into more limited bandwidth networks requires increased use of compression. However, compression processing requires computation time that can introduce delay in the sending and receiving of video. This delay, if it becomes noticeable, can perceptibly interfere with interactivity.
- Standards. H.323 and the MBone tools use international standards and thus are globally interoperable. In MPEG-2 video conferencing, camera formats are evolving. MPEG-1 is often used for streaming video, described below. Internet2 projects are using MPEG-2 for videoconferencing. MPEG-2 hardware encoders cost from $5,000 to $30,000. Hardware decoders can cost slightly less. This does not include the costs for the cameras and microphones necessary for a videoconferencing environment, however, and camera quality is very important with MPEG-2. There are no software decoders for MPEG-2 videoconferencing—only for MPEG-2 streaming. Popular MPEG-2 vendors include Optrevision, Optibase, Minerva, and Cisco (via its PiStream line). MPEG-4 is a new standard providing a wide range of quality and data transfer rates. Its initial commercial focus is video-on-demand streaming at a quality higher than that of MPEG-1 but at only 300–400 Kbps.
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Visibility, Security, and Floor Control

Visibility

It’s not much of an exaggeration to say that there is no security with videoconferencing technologies. Often the only thing an institution needs to join a conference is an address and a PIN, not unlike joining an audio conference-call service. A standard for H.323 is emerging, called H.235, but it doesn’t cover security issues used on most campuses. For the other technologies there may be vendor-specific solutions, but much work remains to be done before we will have appropriate authentication, authorization, and privacy services for videoconferencing.

Security

One of the primary reasons videoconferencing is very intolerant to packet loss. Streaming video, both live and on-demand, usually has a client-side buffer of a few to several seconds so that if data are lost on the network, there will be time to request redelivery. For interactive videoconferencing, large buffers cannot be used and thus other techniques must be developed. One such method is to avoid packet loss in the first place. Network quality of service (QoS) allows the marking of certain traffic, such as video, as higher priority than other traffic, such as e-mail. This “fast lane” through the network will help avoid congestion and packet loss at routers. Implementing QoS across multiple autonomously managed networks is still a research project.

Privacy

It is said that there is no network challenge that multicast cannot make harder. Therefore, although multicast is enabled in national backbones such as Abilene and MCVIs, Cisco and BBNs, all of the regional networks support multicast, and very few campuses provide wide support. Before the Internet backbone environments can be widely deployed, multicast support needs to improve.

Videoconferencing

Streaming Video Technologies and Issues

Streaming video, both live and on-demand, includes a wide range of encoding options and data rates (starting at 25.8 Kbps for dial-up users to over 200 Mbps for high-definition television). The network quality challenges for streaming video are somewhat less problematic than those for interactive videoconferencing. As noted above, buffers allow the buildup of images on the local machine. If any information is lost in transit, it can be requested for retransfer and inserted into the stream in time. Whereas all videoconferencing requires real-time encoding, streaming services can be less than real-time to allow for high levels of compression. Asymmetric encoding means that the encoding process takes longer than decoding. Apple QuickTime, with Sorenson encoding, is an example of asymmetric encoding.

As with videoconferencing, higher education institutions should consider several issues when using streaming video:

- Production rules. Lighting and other production values increase in importance as the quality of the transmitted image improves. For example, shadows from overhead fluorescent lights may not be noticeable at a 50 Kbps transmission rate but stand out clearly with MPEG-2-encoded streams.
- Standard. Choosing a standard to use for encoding can be difficult. MPEG-4 offers the promise of being the standards-based solution. However, the standard is not complete, and there are not a large number of vendor-supported products. If an institution has a collection of film or video files that it wants to put online, should it wait for MPEG-4 or should it start today with MPEG-1 or MPEG-2 and re-code later?
- File sharing. The attention gained by peer-to-peer technologies such as Napster, Gnutella, and Freenet has focused on their use for sharing audio files in MP3 format (the audio standard within the MPEG encoding). Several campus networks support multicast, and very few campus networks provide wide support. Before the Internet backbone environments can be widely deployed, multicast support needs to improve.

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Storage

How does one search across video content? There are manual techniques, including assigning metadata tags to video files. In addition, the Dublin Core and MPEG-7 are emerging architectures for indexing media content. MPEG-7 (unlike MPEG-1, MPEG-2, or MPEG-4) refers to an indexing approach as opposed to a content-encoding standard. There are also ways to automate searches based on image content. Research projects such as Informedia at Carnegie Mellon University (http://www.informedia.cs.cmu.edu/) and commercial offerings such as Virage (http://www.virage.com/) offer means to search for content based on characteristics such as color, motion, and shape, text on the video, voice-to-text conversion, colors, shapes, and even face recognition. This allows someone to query for “President George W. Bush standing in front of a red car.”

Dozens of companies provide streaming video services, among them Apple (QuickTime), Microsoft (Windows Media), IBM (VideoCharger), Cisco (IPTV), and RealNetworks (RealPlayer).

Other Digital Video Challenges

Implementations of digital video technologies also face a number of non-technical issues, including copyright management and enforcement. Many of the social clues or actions expressive in face-to-face discussions or even phone calls are not available today in videoconferencing. For example, something as simple as slamming down the phone receiver to make a point doesn’t necessarily have an equivalent action in videoconferencing. Software-based systems that prompt “Are you sure you want to quit?” and then take several seconds to shut down do not have the same satisfying effect.

Eye-to-eye contact is also difficult due to the separation of the monitor and the camera. Videoconferencing users typically find that they stare into the
The future for streaming video includes innovations such as “clickable images,” which will facilitate navigation within video streams and to external information sources.

Conclusions

Current research laboratory work can give us some idea of where videoconferencing technology may be headed in the next five to ten years. For example, the University of North Carolina at Chapel Hill, with partners from Brown University and the University of Pennsylvania, is developing the “Office of the Future” (<http://www.cs.unc.edu/Research/stc/office/>). The prototype environment consists of remote sites connected over a high-performance network to simulate adjacent cubicles. Several video cameras in each location capture the local images, which are then rendered into a moving, three-dimensional, life-size image presented on a display at each “telecubicle.” One current problem is that the oversized LCD shutter glasses, required to achieve the 3D effect, can interfere with interaction. In addition, the available processing power is not yet able to generate full-motion video, so any movement is jerky.

The future for streaming video includes innovations in content and delivery. There will be a wide availability of video content with “clickable images,” which will facilitate navigation within video streams and to external information sources. For example, clicking on a scene in a movie could lead to more details on the actors. In addition, innovations in compression will lead to video delivered to cellular phones. Internet2 advanced networks provide a testbed for these innovative uses of digital video. Colleges and universities are taking advantage of this opportunity by making significant investments in digital video applications. Research, teaching, and learning can all benefit from the uses of digital video in both collaboration and information dissemination. Although we cannot expect the technology to fully stabilize anytime soon, wise investments will lead to a better understanding of the future potential of video-based applications. But in addition to the technical hurdles, institutions must understand and address the social and policy challenges. Copyright and privacy issues will be worked out through dialogues across higher education and in the cooperative implementation of standards and practices. In this way, we can deploy the “killer app” of digital video to transform “Dilbert’s nightmare” into a highly useful and desirable method for teaching, learning, collaboration, and research in higher education.

Note

1. Whereas encoding is the process of turning video content into digital content, decoding is the process of converting the digital content into a format suitable for viewing on a monitor. A video server is a device used to store and make available digital video content.