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XUNET EXPERIMENTAL HIGH-SPEED NETWORK TESTBED

CRADA 1136, DOE TTI#92-MULT-020-B2

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Abstract

XUNET is a research program with AT&T and other partners to study high-speed wide area communication between local area networks over a backbone using Asynchronous Transfer Mode (ATM) switches. Important goals of the project are to develop software techniques for network control and management, and applications for high-speed networks. The project entails building a testbed between member sites to explore performance issues for mixed network traffic such as congestion control, multimedia communications protocols, segmentation and reassembly of ATM cells, and overall data throughput rates.

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Background

Computer and networking researchers at Sandia have extensive experience in protocol tuning, wide-area networks (required to link its two widely separated sites), security and encryption techniques, and video conferencing and collaborative engineering applications. Sandia also has many activities in vector and massively parallel supercomputing that can offer a demanding, yet realistic test of network performance for high-performance applications. Those activities include both hardware and software platform development and diverse user applications. Recognizing that DOE national laboratories like Sandia could contribute to the ongoing and future activities in AT&T's eXperimental University NETwork (XUNET) testbed (Figure 1), AT&T invited Sandia (as well as Lawrence Livermore National Laboratory) to participate in the project.

In 1992, Sandia centralized its supercomputers in Albuquerque under its Supercomputer Consolidation Project. A major result of that project is a DS3 communication link connecting the Livermore and Albuquerque sites at 45 megabits/second (Mbps). Sandia is committed to participate actively in high-speed networking research and development, so that it can quickly incorporate new networking technologies into its production networks for fulfilling its DOE mission, as well as influence new directions for commercial products. Sandia decided that it could participate more effectively in advanced networking research and development by joining the XUNET testbed after having the network extended from Oakland to Livermore, a distance of about sixty kilometers. Therefore, in 1992 Sandia and AT&T reached a CRADA agreement that Sandia would join the XUNET testbed.

Project Description

The telecommunications industry is using Asynchronous Transfer Mode (ATM) switches, which were invented at AT&T, to build the next-generation national telephone network, because of ATM's flexibility to carry voice, video, and data communications simultaneously at high speed. XUNET is a project at AT&T Bell Laboratories to study high-speed communication between local-area networks over a wide-area backbone built with ATM switches. Important goals of XUNET are to develop software techniques for network control and management, as well as applications such as video conferencing and collaboration tools for use on high-speed networks. Multimedia applications involving video and audio data streams are an important focus, since they will play a central role in future commercial network service markets. The XUNET project entails building a testbed between member sites to explore performance issues for mixed network traffic such as congestion control, multimedia communications protocols, segmentation and reassembly of ATM cells, and overall data throughput rates. Specific goals of the CRADA between AT&T and Sandia are:

- To develop a HIPPI-to-XUNET adapter (HXA) for performing high-throughput data transfer experiments between Cray supercomputers and RISC workstations at different XUNET sites.
- To develop hardware and software for integrating high-speed local-area networks into the XUNET wide-area backbone.
- To enhance network performance on the XUNET testbed by protocol tuning and application optimization.
- To understand potential new real-time video conferencing and collaborative engineering software applications for high-speed networks such as the XUNET testbed.
- To develop XUNET network management tools to visualize ATM network problems, control the network, and reconfigure the network if necessary, all remotely.

Accomplishments

HIPPI-to-XUNET Adapter: Linking widely separated high-performance computers—so that they can be used concurrently to solve challenging computational problems—is one goal for commercial data networks. HIPPI (High-Performance Parallel Interface) is a widely used technology for connecting high-performance computers to local-area networks. The default local-area network configuration at XUNET sites uses an FDDI architecture (Figure 2). The University of Illinois at Urbana-Champaign and University of Wisconsin at Madison sites also connected a Cray supercomputer and a high-performance workstation to the XUNET backbone through a HIPPI local-area network. That entailed building a HIPPI-to-XUNET Adapter (HXA), which is a line card in the XUNET ATM switch that interfaces to a HIPPI switch (Figure 3). The HXA consists of two channels, one that takes ATM cells from the line card and passes them through an Xframe buffer to the HIPPI switch, and one that takes HIPPI packets from the HIPPI switch and passes them to the XUNET switch as ATM cells (Figure 4). Sandia built the enclosure and power conditioning, and assembled complete units for the HXA. AT&T and its XUNET partners achieved data throughputs up to 280 Mbps in experiments between the Cray supercomputer at the University of Illinois at Urbana-Champaign and the high-performance workstation at the University of Wisconsin, thereby validating the HXA design. However, HXA development was dropped when it became evident that a Forum-to-XUNET adapter (FXA) being developed in another task was the preferred approach for integrating high-speed local-area networks into the XUNET wide-area backbone.

ATM WAN/LAN Integration: For many of the same reasons that ATM technology is being deployed for wide-area backbones, markets for ATM products for local-area networks are growing rapidly. A particularly attractive feature of an integrated wide-area/local-area network that utilizes ATM technology throughout is the potential for low latency (round-trip delay time) for interactive multimedia applications.[1] Sandia proposed that AT&T and Sandia jointly develop an interface that can integrate ATM local-area networks into the XUNET backbone. Subsequently, AT&T and Sandia developed a Forum-to-XUNET adapter (the ATM Forum is defining the standards for ATM networks), which is a line card in the XUNET switch to connect ATM local-area networks to XUNET. Using a Forum-to-XUNET Adapter (FXA), workstations with ATM host adapters can be connected to the XUNET backbone either directly to an XUNET switch, or through a FORE Systems or other ATM-Forum-compliant ATM local-area switch connected to an XUNET switch (Figure 5); workstations with FDDI interfaces can still be connected to XUNET through the default local-area network configuration. Using the FXA, we have established IP (Internet Protocol) connectivity using permanent virtual circuits (PVCs) between ATM local-area networks over XUNET. In addition, we worked with researchers at the University of Illinois at Urbana-Champaign to develop a proxy signaling agent that translates between the call-setup signaling protocols for ATM-Forum-compliant switches and XUNET switches, which have different cell formats, to support Switched Virtual Circuits (SVCs). We successfully demonstrated that the proxy agent supports signaling across a network consisting of both ATM-Forum-compliant switches and XUNET switches. Availability of SVCs across integrated wide-area/local-area networks is critical to the commercial success of all ATM network services.

High-Performance Network Protocols: Availability of a high-speed physical communications link is not sufficient for ensuring that data can be transferred reliably and with high throughput between sites. The latency and bit error rate can degrade network performance if protocols for higher layers, such as the Network and Transport Layers, that operate on top of the physical communications and data link layers are not robust and versatile. Furthermore, it is important to develop efficient protocols that are flexible, portable between different computer platforms, and based on modern object-oriented programming methods. Ideally, they also must address new services such as multicast and Quality of Service, which are especially important for delivering video and audio. We produced several releases of SandiaXTP,[2-14] an implementation of the

Xpress Transport Protocol (XTP) that promises to be especially attractive for interfacing high-speed local-area networks to wide-area networks, for which widely varying network requirements are typical. In addition, experiments demonstrated that XTP is a viable means for multicast delivery of video and audio.

Desktop Video Conferencing and Multimedia Tools: Collaboration tools such as desktop video conferencing, and delivery of video and audio for entertainment and educational purposes, are just two examples of multimedia applications that will a powerful market drive for high-speed network services, both for the commercial sector and for DOE Defense Programs. We have made several valuable contributions to the XUNET project in this area. Those contributions include: (1) Distributed Audio Video Environment (DAVE),[15] a toolkit for building multimedia applications such as desktop video conferencing; (2) a video archival server for storing and delivering on-demand videos and similar multimedia over a network; and (3) techniques for traffic control for real-time Variable Bit Rate (VBR) traffic, of which video is a key example.

After developing the basic DAVE toolkit (Figure 6), we built a desktop video conferencing application which we successfully demonstrated on XUNET. To provide real-time Quality of Service essential for video applications, we incorporated the Tenet Real-Time Protocol Suite from the University of California at Berkeley into the operating systems of the computers involved in the development of the video conferencing application. The Tenet protocols provide guaranteed performance data delivery (and signaling) in the local-area networks, while the additional mechanisms built into XUNET switches, such as priority virtual circuits for real-time traffic, will provide guaranteed performance over the ATM wide-area backbone.

Sandia's video archival server allows users from remote XUNET sites to check out and view recorded lectures and seminars stored on the server. The videos are typically MPEG-compressed for efficient data storage. Working with researchers at the University of Illinois at Urbana-Champaign, we successfully delivered MPEG-compressed video over the network, both locally and to the university over XUNET, to a client application based on a World Wide Web browser that plays the video directly as it receives it instead of storing it locally first. (Storing the video first results in unacceptable delay times before play and extremely large data storage requirements.) The FXA line card played a key role in integrating the local-area networks and the XUNET wide-area backbone for this development work.

For VBR data streams such as those from our video archival server, an important question is how to balance high utilization of the network bandwidth with reasonable Quality of Service (QoS).[16-30] The former requirement impacts revenue generation from the service, and the latter impacts performance and customer satisfaction. We have developed two new approaches for traffic control that attempt to strike a more efficient balance between the above tradeoffs than previous approaches. The first approach, Renegotiated Deterministic VBR, is based on deterministic guarantees with client-controlled renegotiation of QoS parameters and graceful adaptation during overload periods. Evaluation of the scheme for MPEG-compressed video showed that, even with simple renegotiation policies and relatively low renegotiation frequencies, high network utilization (50-80%) can be achieved. For traffic that is bursty over long intervals, that represents a 100-150% improvement in network utilization compared to existing deterministic service. Compared to statistical and predicted service, our approach allows more graceful and client-controlled QoS degradation during overload periods. The second approach, Hybrid Bounding Interval Dependent, captures the correlation structure and burstiness of video traffic, but unlike deterministic schemes achieves a statistical multiplexing gain by exploiting the statistical properties of deterministically bound data streams. That can result in average network utilizations as high as 86%, while retaining reasonable Quality of Service for MPEG-compressed video in realistic situations.

Network Management Tools: Performance monitoring, troubleshooting problems, and other network management functions are essential for any network, especially those delivering commercial services. One popular network management protocol is the Simple Network Management Protocol (SNMP). SNMP agents, plus the associated Management Information Base (MIB), can be queried for the performance (e.g., throughput and errors) and health of network-based equipment such as switches, routers, and servers. Sandia built SNMP agents and MIBs for the XUNET switch and the router connecting those switches to FDDI local-area networks. We also built a library of C-callable SNMP routines and an assortment of SNMP-based text and graphical tools to retrieve, browse, set, and graphically monitor managed information for equipment on the XUNET testbed with SNMP agents.

Project Examples Suitable to Show and Tell or Display

Desktop video conferencing, remote visualization, and similar graphics-based applications are all suitable for display, but they do require significant advanced preparation and availability of a high-speed network connection. Remote visualization capabilities developed on XUNET were displayed in a highly successful demonstration to Vice President Gore at AT&T Bell Laboratories on May 3, 1993; Sandia was involved in that demonstration.

Benefits to DOE

In response to changing fiscal and political climates, DOE Defense Programs is moving toward creating a "virtual enterprise" for fulfilling its mission of stockpile stewardship, including production, oversight, and dismantlement. Environmentally conscious product realization, weapon surveillance, material disposition, and stockpile management will rely more on information-based resources, which, to reduce cost and response time, will be accessible across the complex via distributed information systems linked by high-speed, secure networks connecting the laboratories and facilities. Also, as more emphasis is placed on computer simulations for engineering development, the ability of high-speed networks to allow the use of massively parallel and vector supercomputers, database storage servers, and workstations—potentially at widely separated DOE locations—to address a single problem will be increasingly important as expensive resources are centralized at a few sites. For example, knowledge derived from computational manufacturing and virtual prototyping must be readily accessible throughout the complex in an efficient and transparent manner. Furthermore, that knowledge must be integrated into a larger enterprise which brings together the diverse capabilities of the facilities, and it must be preserved for dissemination for subsequent stockpile stewardship applications.

The XUNET project addresses the development of distributed information systems that AT&T ultimately will commercialize. Those commercial systems are similar to those being deployed by DOE Defense Programs to link together staff and facilities at DOE sites and other locations. A prime example is SecureNet, a classified network linking LANL, LLNL, and the two Sandia sites that will be used for collaborative design environments and high-performance computing applications directed at Science-Based Stockpile Stewardship. Just as for XUNET, DOE Defense Programs is developing and integrating technology and tools for distributed applications such as component design and fabrication, plus the information architecture tying the system elements together.

Successful deployment of a DOE Defense Programs virtual enterprise for Science-Based Stockpile Stewardship is crucially dependent on early access to information technology like that being developed by industry and academia for XUNET. Sandia's (and Lawrence Livermore's) participation in XUNET greatly facilitated partnerships with industry and academia and was an effective vehicle to bring their advanced technology in distributed information systems to DOE laboratories. It also created an opportunity for the laboratories to influence the technology that companies commercialize, to maximize the benefit to DOE Defense Programs.

DOE Facility Point of Contact for Project Information

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Figure 1: Map of XUNET sites. The cross-country link consists of 45 Mbps links using AT&T's Accunet Reserved Service. The connected sites include University of California at Berkeley and Lawrence Berkeley National Laboratory (1), Sandia National Laboratories and Lawrence Livermore National Laboratory (2), University of Wisconsin at Madison (3), University of Illinois at Urbana-Champaign (4), AT&T Bell Laboratories, Murray Hill (5), and Rutgers University (6).

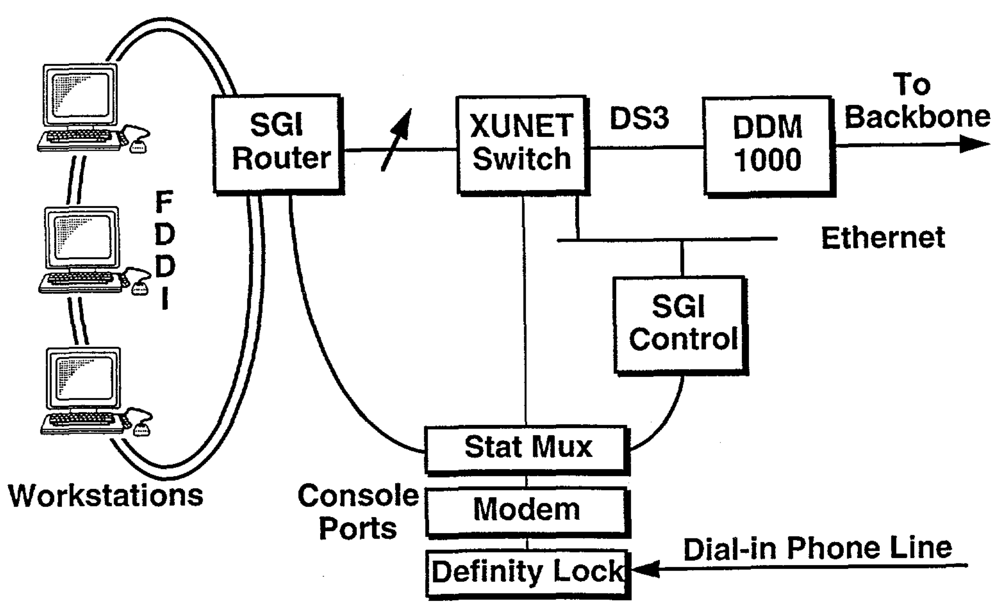

Figure 2: Default XUNET architecture using FDDI local-area networks. SGI workstations are used as routers to connect an XUNET switch to the FDDI ring and to control the switch. The switch can be accessed through a dial-in console port.

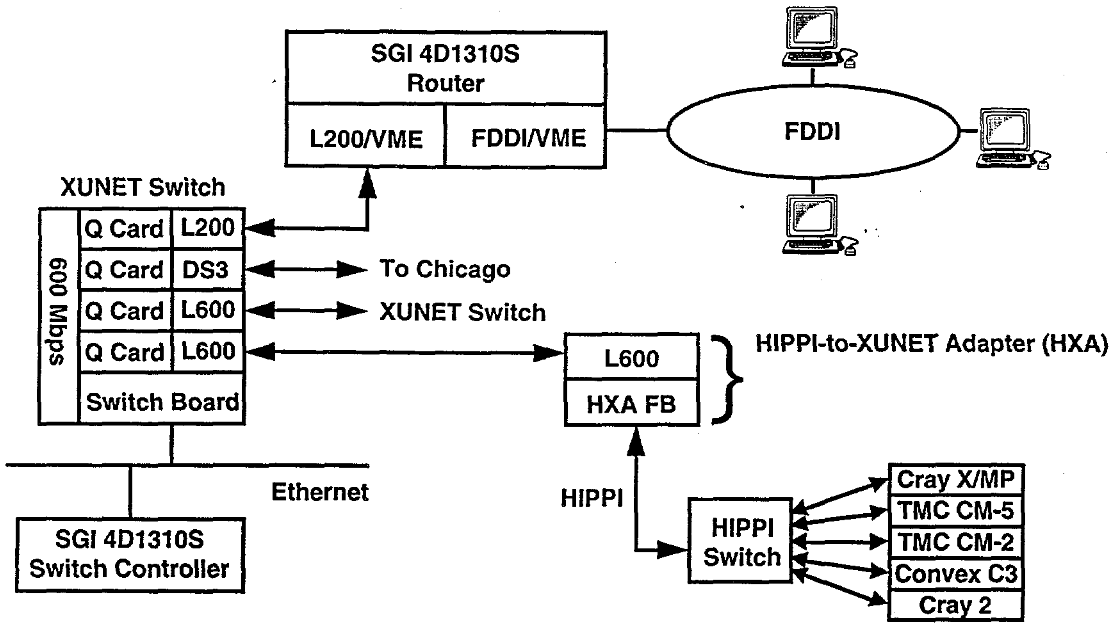

Figure 3: XUNET Site Map: UIUC/NCSA example. The XUNET switch consists of queue cards and line cards connected to a 600Mbps bus. A HIPPI-to-XUNET Adapter (HXA) allows an L600 (600 Mbps) line card to be connected to a HIPPI local-area switch with supercomputers attached.

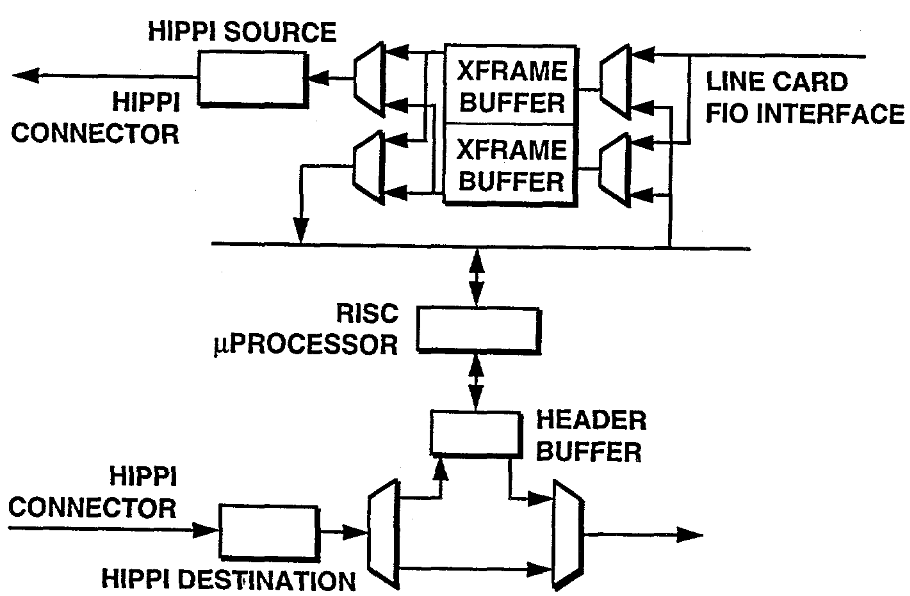

Figure 4: HIPPI-to-XUNET Adapter. The HXA consists of two channels, one that takes ATM cells from the line card and passes them through an Xframe buffer to the HIPPI switch, and one that takes HIPPI packets from the HIPPI switch and passes them to the XUNET switch as ATM cells, all controlled by a RISC microprocessor.

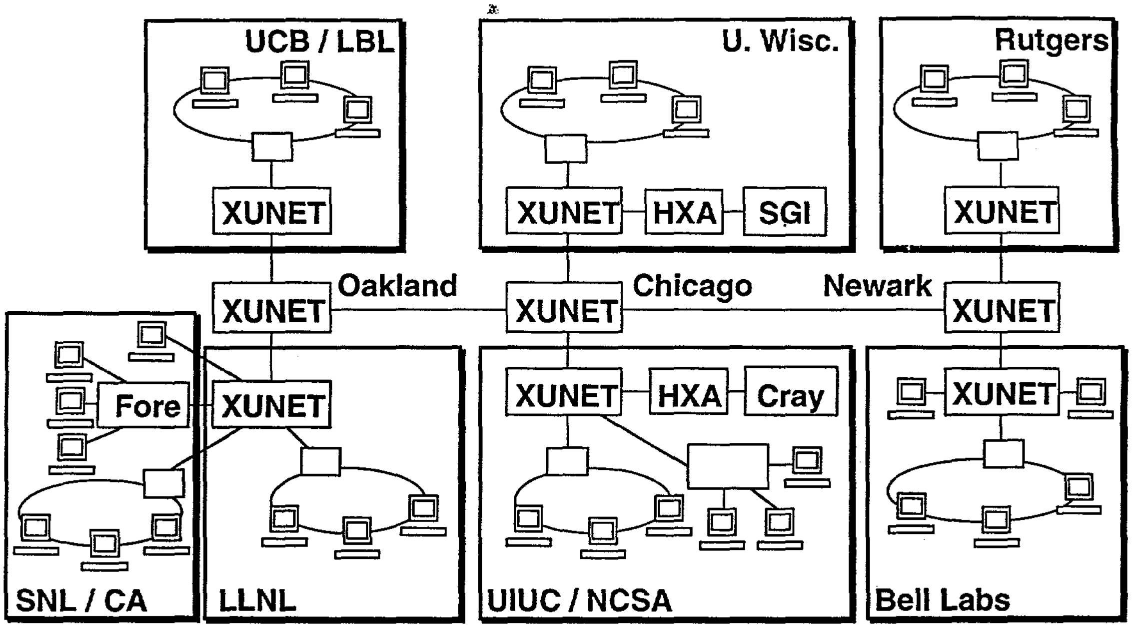

Figure 5: Integrated ATM WAN/LAN. Using a Forum-to-XUNET Adapter (FXA), workstations with ATM host adapters can be connected to the XUNET backbone either directly to an XUNET switch, or through a FORE Systems or other ATM-Forum-compliant ATM local-area switch connected to an XUNET switch; workstations with FDDI interfaces can still be connected to XUNET through the default local-area network configuration.

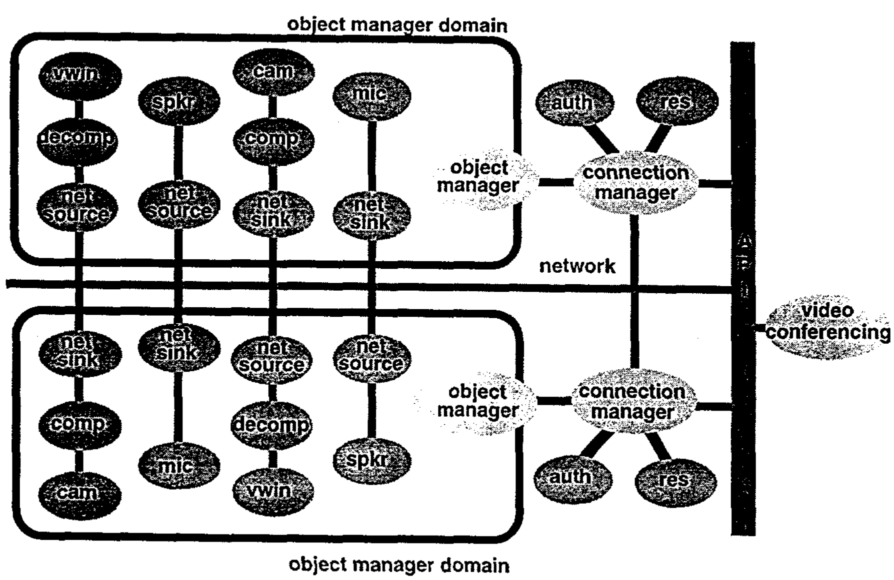

Figure 6: Distributed Audio Video Environment. DAVE is a toolkit for building applications from distributed objects. Using distributed objects controlled by connection managers and object managers, functions such as controlling a laser remotely over a network or delivering audio and video over a network for desktop video conferencing can be created in a plug-and-play fashion.

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