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Deployment of the National Transparent Optical Network Around the San Francisco Bay Area

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Abstract

We report on the deployment and initial operation of the National Transparent Optical Network, an experimental WDM network testbed around the San Francisco Bay Area, during the Optical Fiber Conference (OFC '96) held in San Jose, CA. The deployment aspects of the physical plant, optical and SONET layers are examined along with a discussion of broadband applications which utilized the network during the OFC '96 demonstration. The network features dense WDM technology, transparent optical routing technology using acousto-optic tunable filter based switches, and network modules with add/drop, multicast, and wavelength translation capabilities. The physical layer consisted of over 300 km of Sprint and Pacific Bell conventional singlemode fiber which was amplified with 11 optical amplifiers deployed in pre-amp, post-amp, and line amp configurations. An out-of-band control network provided datacom channels from remote equipment sites to the SONET network manager deployed at the San Jose Convention Center for the conference. Data transport over five wavelengths was achieved in the 1550 nm window using a variety of signal formats including analog and digital signal transmission on different wavelengths on the same fiber. The network operated throughout the week of OFC '96 and is still in operation today.

Overview

Next generation, wide area optical networks will employ wavelength division multiplexing (WDM) along with optical routing and optical amplification to achieve a higher capacity, more affordable, telecommunications information infrastructure.

The National Transparent Optical Network Consortium (NTONC) with financial support from the U.S. Department of Defense Advanced Projects Research Agency (DARPA) is developing a prototype WDM network which will encompass the San Francisco Bay Region. The all-optical network will demonstrate critical WDM technologies and network management concepts required for terabit optical networks for U.S. DoD, information industry, and consumer communications.

The network backbone will have network access nodes initially at Pacific Bell, Sprint, University of California Berkeley, and Lawrence Livermore National Laboratory as illustrated in Figure 1. Tributaries to additional user sites will be added to allow real applications to be developed and tested across the network. Users will rely on the high quality of service in the backbone to develop and promote these broadband applications.

The project focus on both applications and technologies will result in strategies for commercial deployment of broadband services and optical network technologies.

The NTONC originated in 1994 and its members include: NORTEL (Northern Telecom), Sprint, Pacific Bell, GM Hughes Research Labs, Lawrence Livermore National Laboratory, University of California San Diego, Rockwell Science Center, Uniphase Telecommunications Products, Case Western Reserve University and Columbia University. The NTONC is a descendant of the Optical Networks Technology Consortium[1] (ONTC), with changes in membership that reflect changes in program emphasis. The consortium has created teams in the areas of: Operations, Administration & Management, Network Studies, Network Implementation, and Network Applications, in order to provide additional focus and organizational structure for these activities.

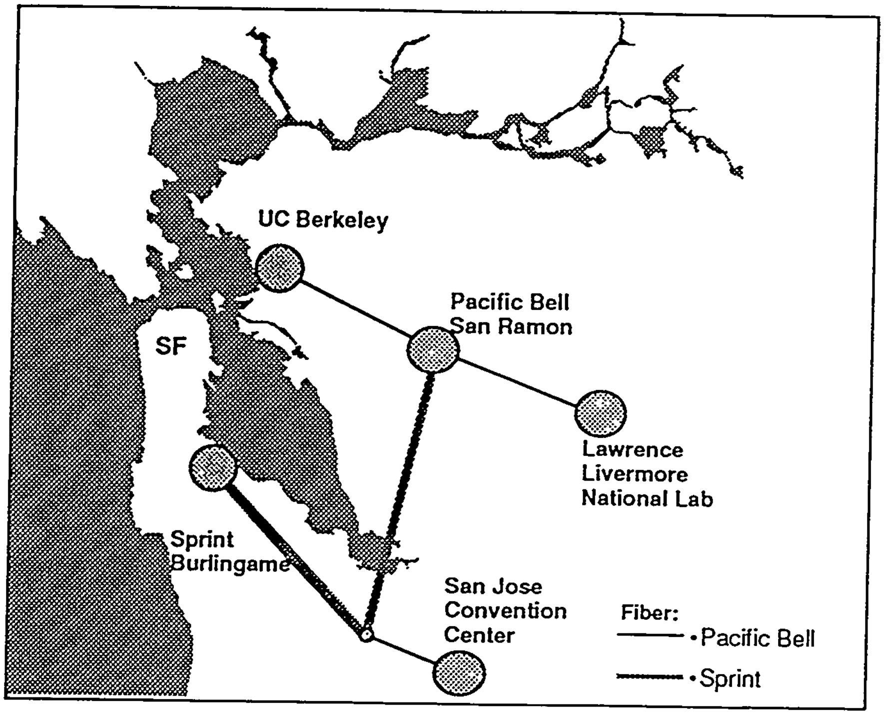

Figure 1. Map of the National Transparent Optical Network deployed around the San Francisco Bay Area for OFC'96.

Optical Layer

The optical layer for the National Transparent Optical Network(NTON) includes the fiber plant, optical amplifiers, wavelength division multiplexing components, optical terminal equipment, optical switching equipment, and passive fiber components. The optical layer provided connectivity to broadband application sites from the San Jose Convention Center while showcasing the advanced optical networking technologies deployed in the network. The configuration of the optical layer for OFC '96 is illustrated in Figure 2.

The NTON fiber plant is comprised of conventional, nondispersion shifted singlemode fiber within the Sprint and Pacific Bell fiber infrastructures. The optical fiber loss was fully characterized on a segment by segment basis. The network locations of the optical amplifiers was engineered based on the fiber loss, the number of wavelengths across a span, the amplifier gain and noise characteristics, and the effects of gain tilt and noise accumulation from amplifier cascades.

In the case of a balanced four wavelength span, optical amplifier output of +8 dBm, and a minimum signal level of -20 dBm, the maximum desired loss between optical amplifiers with margin was 18 dB. The selection of the central office locations for optical amplifier placement was based on this criteria.

A standard NORTEL optical amplifier product was selected for deployment in the network. The optical amplifier is remotely configurable by software as a line amp or a post amp with a maximum output of +8 dBm or +11 dBm, respectively. A total of 11 optical amplifiers were installed at node sites, central offices, and CEV's in pre-amp, post-amp, and line-amp configurations as required by the optical power budgets.

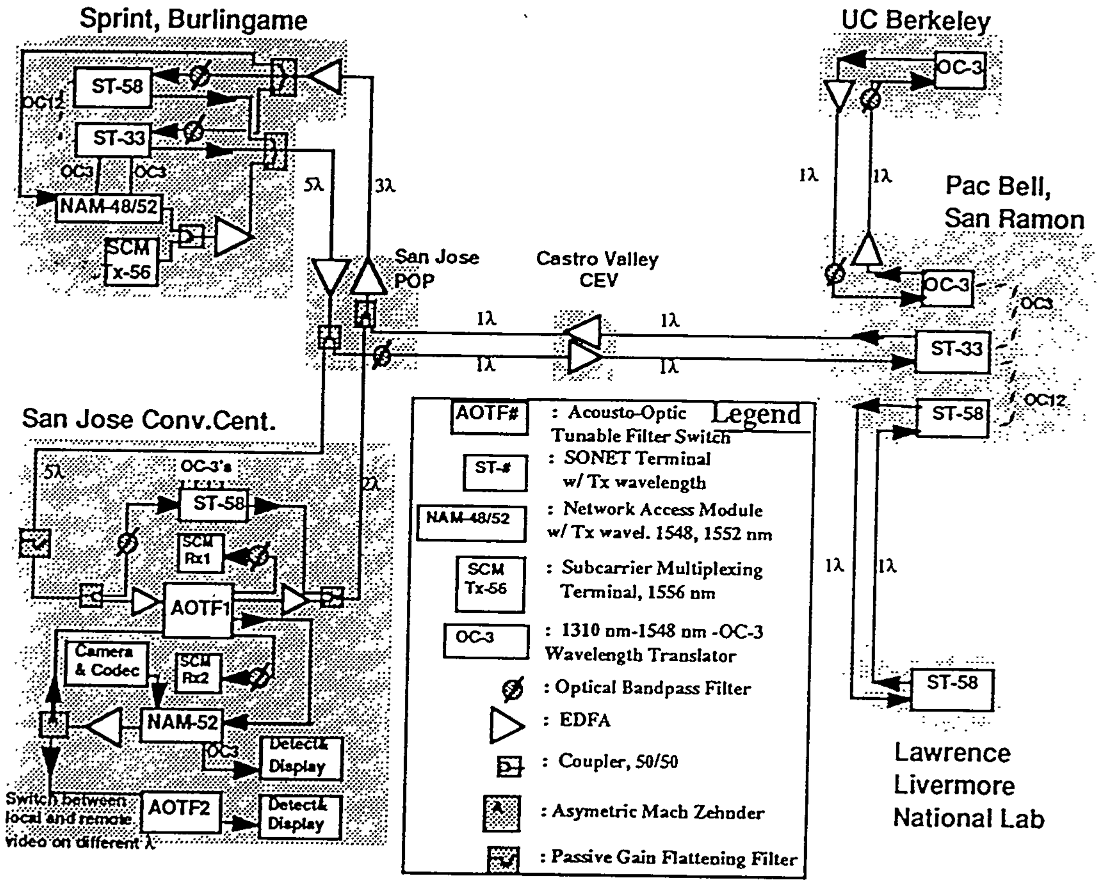

Figure 2. Optical layer connection diagram of the NTON during OFC.

Cascades of optical amplifiers experience gain tilt and usually require gain equalization for proper multiwavelength operation. For the OFC '96 network, one multiwavelength span in the network had three cascaded optical amplifiers. The gain uniformity across this amplifier cascade was maximized by proper adjustment of the launch powers. A prototype gain flattening filter was also installed and evaluated on the multiwavelength fiber span entering the San Jose Convention Center during the conference. Gain flattening filters can be embedded into the amplifier gain block to achieve optimum amplifier performance. Later, passive fiber gain flattening filters will be deployed throughout the network to equalize the gain across the 1546 nm to 1558 nm bandpass.

Power balancing between the wavelengths was facilitated by the ability to adjust the output power of optical amplifiers remotely with an out-of-band control network. An out-of-band control network was required to manage the operation of the remote optical amplifier sites since detection and demultiplexing to read SONET overhead is not performed at the remote line amp sites. The control network used T1 and 56 Kb/s datacom channels to link operation controllers co-located with remote optical amplifier pairs. The optical amplifiers at the four nodes sites were accessed using shelf-to-shelf cabling to adjacent SONET terminal shelves. In addition to optical amplifiers, the externally modulated high power OC-48 SONET transmitters (HPTX) contain an integral post-amp whose output power is adjustable. The HPTX transmitters have over a 300 km reach on standard, amplified fiber with negligible power penalty.

Emulation of each WDM fiber span was carried out in the Photonics Networking Research Lab at LLNL. An empirical model for the cascaded optical amplifiers spans was developed to help design the network and balance the optical powers to compensate for amplifier gain tilt. The design had to consider the differences in launch powers ranging from -15 dbm to +10 dbm. The Subcarrier Multiplexing and Network Access Module transmitters required post amplification before multiplexing with the HPTX sources.

The bandpass filters used were tunable filters with 1 nm bandpass. The filter elements were the hard-coated type with very low thermal coefficient and drift was not significant. The filters served as wavelength demultiplexers when combined with conventional power splitters.

The 60 km amplified fiber span, between Burlingame and San Jose, supported data transmission on five wavelengths (1533, 1548, 1552, 1556, and 1558 nm) as shown in Figure 3. The 1533 nm and 1558 nm wavelengths carried OC-48 SONET. The 1556 nm wavelength broadcast four channels of subcarrier multiplexed(SCM) FM video, and the 1548 nm and 1552 nm wavelengths transported multiple digital video signals encoded into OC-3 frames. The return path contained two wavelengths (1552 nm and 1558 nm) transmitted from the OFC '96 booth back to Burlingame and a third wavelength at 1533 nm was coupled onto the fiber span in the San Jose Sprint POP.

The SONET connection between Sprint-Burlingame and Pacific Bell-San Ramon at 1533 nm was multiplexed with the other wavelengths on the single fiber pair from Sprint to the San Jose POP. At the San Jose POP, the 1533 nm SONET wavelength was bandpass filtered for the 150 km transmission distance to the SONET receiver at Pacific Bell. The filtering eliminated the other wavelengths which allowed sufficient gain for the 1533 nm SONET wavelength to reach the Pacific Bell node.

The UCB to Pacific Bell leg used wavelength translators[2] between the 1.3 short-haul and 1.5 long-haul window to connect an OC-3 ATM interface at Lawrence Berkeley National Laboratory (LBNL) to the network. Post amps were used on this segment to accommodate the fiber loss. Bandpass filters with 3 nm bandpass were also used to reduce out-of-band optical amplifier noise in this span.

The span between LLNL and Pacific Bell had a single wavelength at 1558 nm that transported OC-48 SONET.

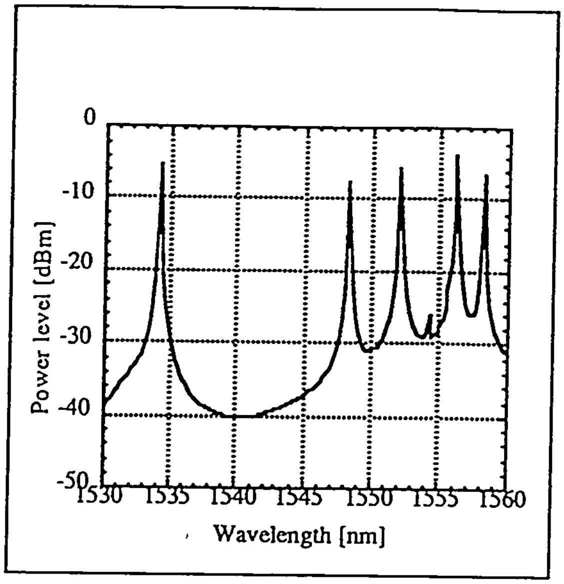

Figure 3. Optical spectrum measured at San Jose POP originating in Burlingame.

SONET Layer

The SONET layer consisted of six commercial NORTEL OC-48 terminals in three linear (point-to-point) configurations as shown in Figure 4. The two terminals at both Burlingame and San Ramon were interconnected back-to-back at OC-12, to allow connectivity between the linear pairs. All tributaries were optical, OC-3 and OC-12, and carried STS-3c payloads. At the time of OFC '96, the OC-48 shelf could be configured with up to four OC-3 or OC-12 tributaries. Stable network synchronization was achieved utilizing stratum clocks at Pacific Bell and Sprint. The terminal at the convention center was loop timed off the Sprint Burlingame terminal connected directly to the stratum clock source and the terminal at LLNL was loop timed off the Pacific Bell stratum clock source. The SONET network was controlled from the convention center floor by a graphical interface product called NetManager running on an HP workstation. The NetManager also connected to the remote optical amplifier sites over an external ethernet network. Operations controllers were placed at San Jose Convention Center (primary) and LLNL (back-up).

The SONET terminals were operational several months prior to OFC '96 at the node sites. Access to install equipment at San Jose Convention Center was limited to three days prior to the OFC '96 exhibition opening. The OC-48 terminal shelf and optical amplifier shelf destined for the OFC '96 booth were placed in a movable rack enclosure at Burlingame a month before OFC '96 for initial site and system testing. A week prior to OFC '96, the rack enclosure was moved to the San Jose POP several miles from the San Jose Convention Center. The fiber loss between the San Jose POP and the Convention Center was emulated with fiber attenuators to ensure the power budget was sufficient. The SONET terminal was site and system tested at the San Jose POP staging location prior to provisioning the SONET terminals. Three days before the opening of the NTON booth at OFC '96, the SONET equipment was moved into the San Jose Convention Center, powered, fibers connected, and operational within a day.

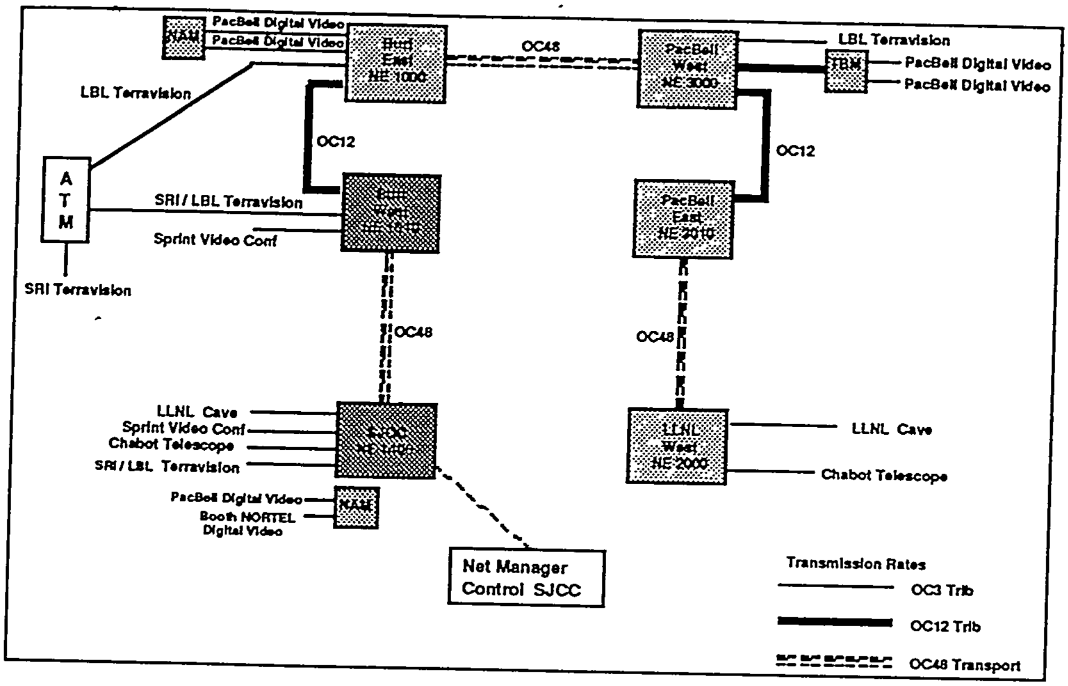

Figure 4. SONET configuration diagram for OFC'96.

Optical Network Reconfiguration

Wavelength selective routing is an essential aspect of transparent optical network reconfiguration. The NTONC is investigating the use of acousto-optical tunable filter (AOTF) switches[3] as an optical switching technology. The AOTF, being developed by Uniphase Telecommunications Products, is a wavelength selective device capable of switching one or more wavelengths in microsecond time scales.

For OFC '96, the AOTF was configured to independently switch, see Figure 5a, up to four wavelength channels spaced by 4 nm in the 1550 nm window. The AOTF's were configured into a dilated 2x2 switch architecture, see Figure 5b, and both digital and analog signals were switched with the device.

Two dilated 2X2 AOTF switches were located in the booth at OFC '96 as part of the optical network technology demonstrations. The first AOTF switched an analog FM video signal on the 1556 nm wavelength being broadcast from Sprint (Burlingame) between two adjacent SCM receivers connected to the output ports of the switch. The state of the AOTF switches was manually controlled through a GUI computer interface. Optical switching was illustrated when the video content instantaneously switched between the video monitors on the SCM receivers.

A second dilated 2x2 switch, AOTF #2 as labeled in Figure 2, allowed OFC '96 attendees to interactively switch, via GUI computer interface, between the video content encoded on the 1550 nm and 1554 nm wavelengths onto a display monitor. The video sources consisted of a video camera setup in the booth and a Pacific Bell Corporate News signals being transmitted from Pacific Bell across the network.

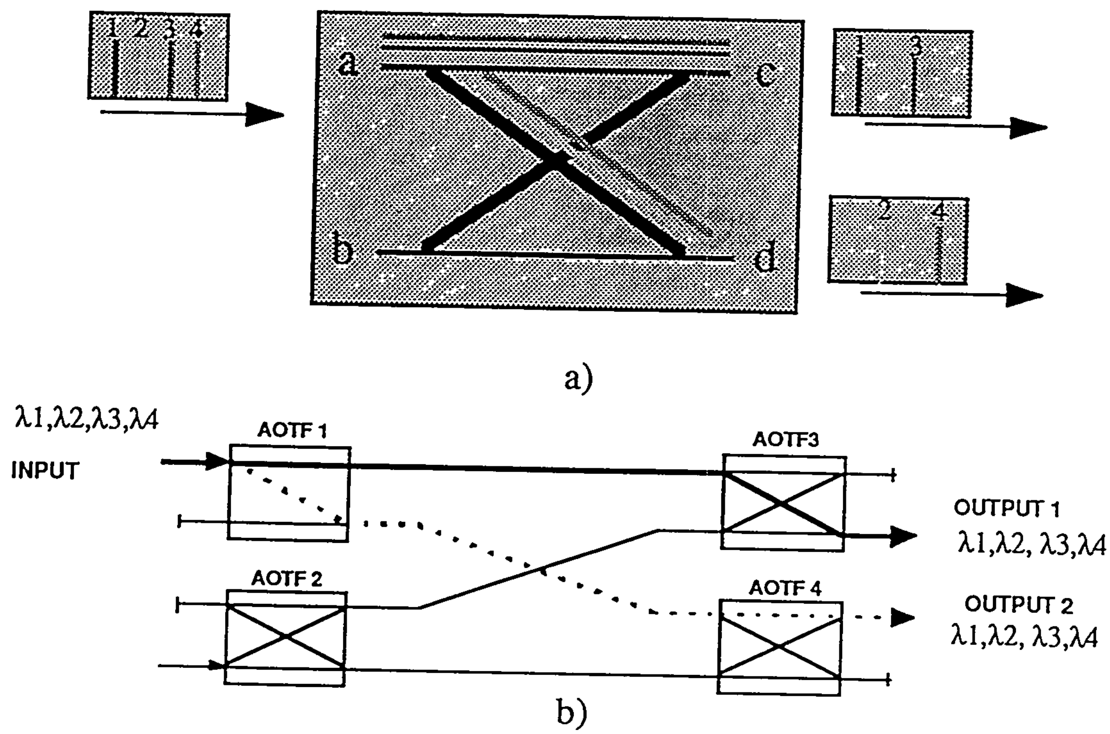

Figure 5. a) AOTF switch functionality b) Asymmetrically dilated 2X2 AOTF switch.

Network reconfiguration was also demonstrated with the Network Access Module (NAM) which has optical add/drop, multicast, regeneration, and electronically selectable wavelength (λ) translation functionality. The NAM is a highly integrated 8λ WDM device that was designed , built, and demonstrated[4,5] under the ONTC program. A functional block diagram of a NAM is shown in Figure 6.

NAM's were deployed at Sprint-Burlingame and at the OFC'96 booth as part of the telemedicine training application (see Figure 11 for the telemedicine connection diagram). Two of the eight available NAM lasers were used to transport signals from Sprint to the OFC 96 booth. The NAM translated two 1310 nm OC-3 tributaries from the OC-48 terminal at Sprint onto NAM wavelengths of 1548 nm and 1552 nm for transport to the OFC '96 booth. Another NAM demultiplexed and detected the two wavelengths in the booth. The NAM internal crosspoint switch was programmed to optically drop either the 1548 or 1552 nm wavelength at one of the NAM optical drop ports. The NAM drop port was connected to an optical receiver, MPEG2 decoder and video display. To demonstrate the NAM selectable add/drop, the NAM was reconfigured by a single keystroke to drop one of the two video sources to the booth display. To demonstrate wavelength translation and optical multicasting, the 1552 nm NAM input was translated to 1550 nm and dropped from the NAM in the booth. The translated channel was then switched by the interactive AOTF switch.

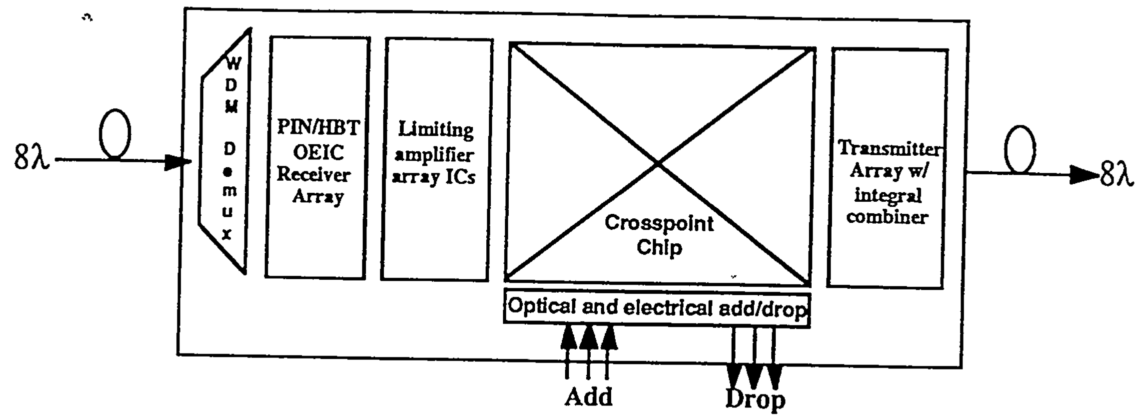

Figure 6. Block diagram of a Network Access Module used at OFC.

NTONC Network Applications

Five applications were integrated and on-line for the OFC 96 demonstration. This successful deployment was the result of significant background work and the coordinated efforts of many intra-organization teams. These applications were successful as a magnet of attention for many of the attendees who were then encouraged to review the technology aspects of the demonstration.

3-D Terrain Visualization with Distributed Servers

Stanford Research Institute's (SRI) TerraVision, a 3-D terrain visualization program that runs on a high performance graphics workstation, was connected to two Distributed Parallel Server Systems (DPSS) to show users a helicopter pilot's eye-view of terrain in a military installation. Figure 7 illustrates the many aspects and connections for this application. One DPSS server was located at SRI's facilities in Menlo Park connected to the Burlingame Spartan ATM switch over the Silicon Valley Test Track. The other server was located at the Lawrence Berkeley National Laboratory (LBNL's) facilities in Berkeley and was connected to the Burlingame Spartan ATM switch over the NTON backbone. The servers were connected via two-way 155 Mb/s ATM links. The 155 Mb/s OC-3 ATM multiplexed signals output from the Spartan switch were then routed over the NTON backbone to the OFC 96 floor. This application demonstrated the ability to provide high quality terrain or battlefield data to a centralized command site from multiple remotely located data servers on a real-time basis. At the close of 2Q96, the TerraVision application is in continuing operation over the NTON between LBNL and SRI.

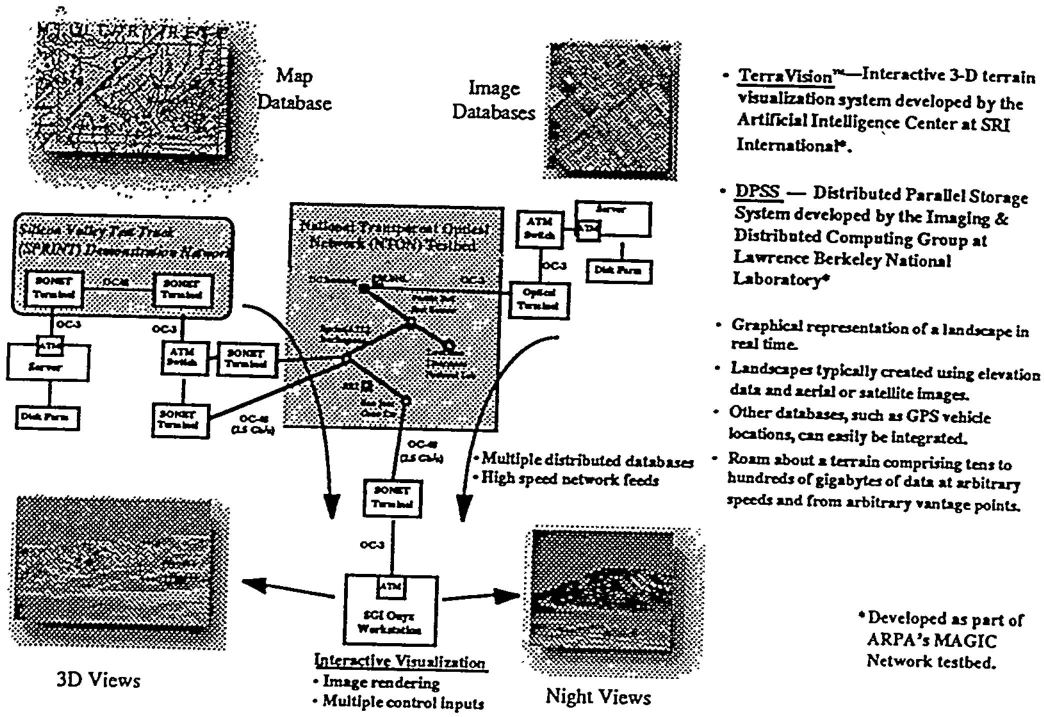

Figure 7. Connection diagram of TerraVision.

Magnetic Fusion Simulation from a Supercomputer

An advanced simulation of magnetic fusion plasma turbulence was run in real-time on a Cray T3D supercomputer in the National Energy Research Supercomputing Center at LLNL and the output was visualized on a high performance graphics terminal at the OFC'96 booth. The two locations were interconnected via a two-way 155 Mb/s(OC3) ATM link through the NTON backbone as shown in the Figure 8 diagram. This application illustrated the concept of remote visualization of simulations from a supercomputing site, possible in real time only when larger bandwidths are available.

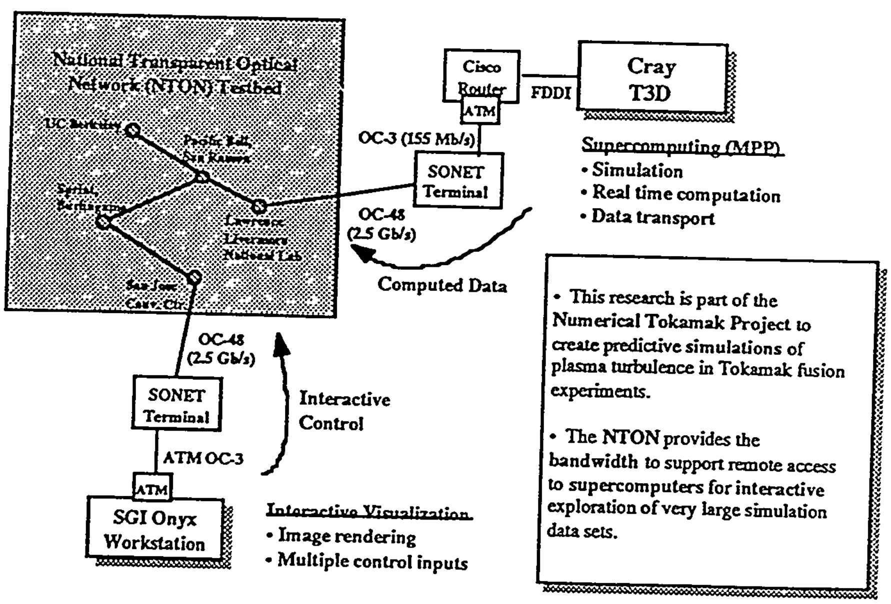

Figure 8. Connection diagram of the Magnetic Fusion Simulation.

Remote Telescope

NTONC collaborated with the Chabot Science Observatory, an agency of the City of Oakland Public School System, to develop a remotely operated solar telescope. The application is shown in Figure 9. The telescope was located at the LLNL site in Livermore with a remote command station at the OFC'96 booth that controlled the pointing direction of the telescope. The connection was via a two-way 155 Mb/s (OC-3) ATM link through the NTON backbone. This application illustrated the concepts of remote data acquisition, remote viewing, and provided insight into use of such facilities for classroom education.

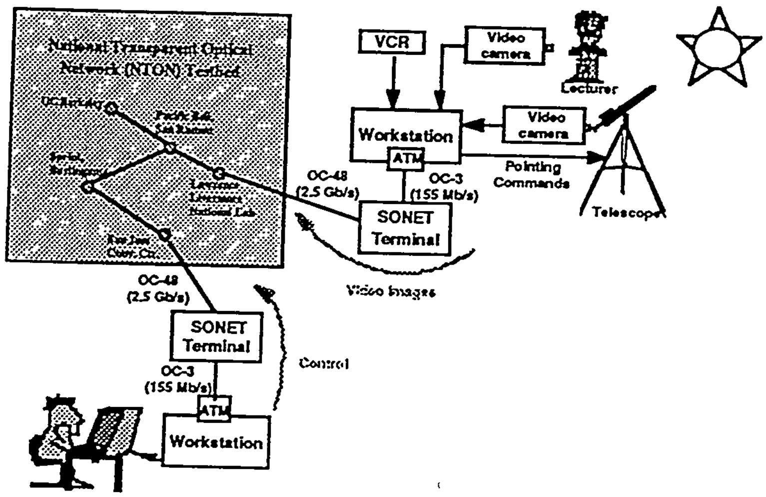

Figure 9. Connection diagram for the Remote Telescope Application.

Broadband Interactive Education/Conferencing

A two-way broadcast quality interactive conferencing link was established between the Sprint Advanced Technology Laboratory in Burlingame and the OFC 96 booth. This link was connected via OC-3 SONET links over the NTON backbone shown in Figure 10. During the scheduled NTON demonstrations, a speaker at the OFC 96 booth held a discussion with a Sprint researcher 50 km away in Burlingame, CA.

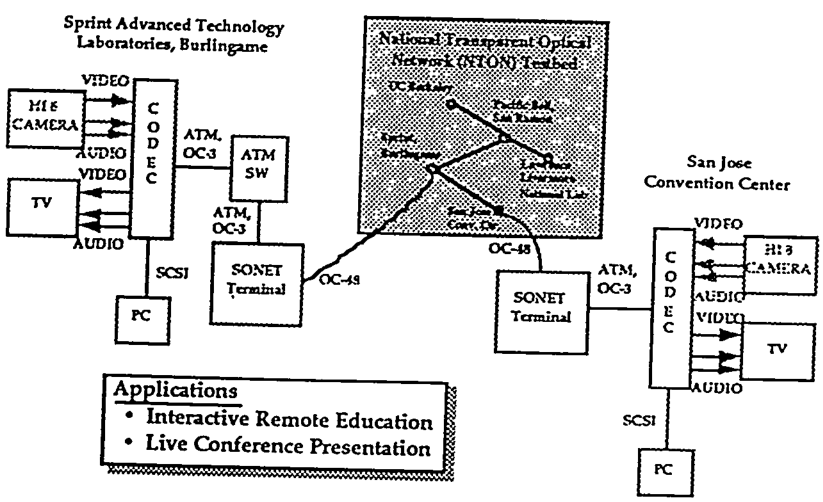

Figure 10. Connection diagram of the Broadband Interactive Education/Conferencing Application.

Telemedicine Training

The telemedicine training application included several high resolution surgical procedures transmitted from two video sources, one located in a Kaiser hospital in Oakland and the other in the Pacific Bell San Ramon Broadband Laboratory. As shown in Figure 11, the data was carried as two MPEG2 data channels on separate OC-3 links from Oakland and San Ramon to the Sprint/Burlingame node. The two 1310 nm OC-3 tributaries were optically added to the NAM at Burlingame for translation to 1548 nm and 1552 nm followed by transport from Burlingame to the OFC 96 floor where the WDM signal was dropped by the second NAM on the conference floor. The NAM was controlled to optically drop either of the two wavelengths and thus switch between the two video feeds with geographic diverse locations onto the single monitor inside the OFC'96 booth. This application demonstrates NAM optical add/drop and optical reconfiguration capabilities.

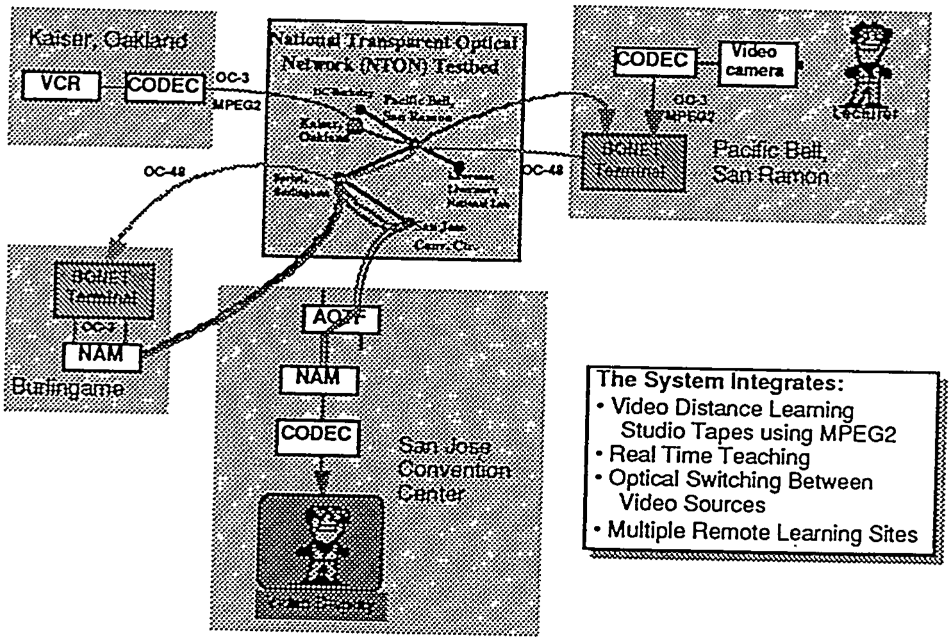

Figure 11. Connection diagram of the Telemedicine Training Application.

Conclusion

A WDM network was deployed around the San Francisco Bay Area for a live network demonstration at the 1996 Optical Fiber Conference. Advanced optical networking technology was deployed and operational including AOTF switches, network access modules consisting of integrated WDM components, and subcarrier multiplexing terminals. Applications utilizing the high bandwidth capability and optical layer dynamic reconfiguration of WDM networks highlighted the technology. After the OFC'96 grand opening, the NTON will continue adding additional connectivity around the Bay Area. The NTON will operate as an 'open test-bed' for application development and new optical technologies.

Acknowledgments

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