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Sandia's Research Network for *Supercomputing '93*: A Demonstration of Advanced Technologies for Building High-Performance Networks*

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Abstract

Supercomputing '93, a high-performance computing and communications conference, was held November 15th through 19th, 1993 in Portland, Oregon. For the past two years, Sandia National Laboratories has used this conference to showcase and focus its communications and networking endeavors. At the 1993 conference, the results of Sandia's efforts in exploring and utilizing Asynchronous Transfer Mode (ATM) and Synchronous Optical Network (SONET) technologies were vividly demonstrated by building and operating three distinct networks. The networks encompassed a Switched Multimegabit Data Service (SMDS) network running at 44.736 megabits per second, an ATM network running on a SONET circuit at the Optical Carrier (OC) rate of 155.52 megabits per second, and a High Performance Parallel Interface (HIPPI) network running over a 622.08 megabits per second SONET circuit. The SMDS and ATM networks extended from Albuquerque, New Mexico to the showroom floor, while the HIPPI/SONET network extended from Beaverton, Oregon to the showroom floor. This paper documents and describes these networks.

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1 Introduction

"The supercomputing conferences are organized by volunteers from academia, government, and industry with a vested interest in high-performance computing and communications; the purpose of the conference is to advance applications of computing technology [13]." This year the conference was held from November 15th through 19th, 1993, in Portland, Oregon. The conference is sponsored by the Association of Computing Machines (ACM) Special Interest Group on Computer Architecture (SIGARCH) and the Institute for Electrical and Electronics Engineers (IEEE) Computer Society Technical Committee on Supercomputing Applications and Computer Architectures. During its short existence, the sixth annual conference brought together the leaders in high-performance computing and provided a showcase for new developments and accomplishments.

The conference draws a spectrum of professionals from industry, government, and academia. Participants experience a setting to share knowledge, arrange future partnerships, and to discover the needs and requirements of potential customers. Therefore, Sandia, and in particular the Networking Departments, participate in the conference for several reasons:

- to focus current networking activities and projects for a highly visible and noteworthy demonstration
- to challenge the capacity and capability of emerging technologies to perform in the high-performance computing and communications environment
- to encourage partnerships with a variety of vendors and to demonstrate the synergies that standards and partnerships enable
- to provide a showcase where various other Sandia departments in California and New Mexico can demonstrate their capabilities and ongoing projects in an environment closely coupled to their computer resources at Sandia.
- to encourage interactions and sharing of knowledge between Sandia experts and their professional peers at other research facilities and in private industry
- to clearly demonstrate Sandia's skills with networking and communications technologies.

Each year, as part of the conference, a team of volunteers constructs a local area network, called *SCInet*, to interconnect the computing resources in the vendor and research exhibits on the showroom floor. Sandia always participates in

this endeavor and expands the network to include wide area connections. Sandia's network extensions demonstrate the frontiers of what is currently possible in high-performance networking and communications for the wide area. Volunteers from Sandia have played major roles in designing and building *SCInet*¹ since its inception at the Albuquerque show in 1991.

Sandia's networking and communications departments have participated in the conference since 1991 when it was held in Albuquerque, New Mexico. Sandia's participation in that show included providing three DS3 (44.736 megabits per second) circuits over an OC-3 SONET (155.52 megabits per second) and a HIPPI gigabit extension over U S WEST provided dark fiber between Sandia's Massively Parallel Computing Research Laboratory (MPCRL) and its booth at the Albuquerque Convention Center [2]. At the following conference in Minneapolis, Sandia demonstrated the prototype technology it was planning to use in its Supercomputing consolidation that was planned for the following spring [12][7]. The network consisted of SMDS based on a prototype AT&T BNS-2000 switch with DS3 (44.736 megabits per second) access [6]. This network provided the longest, fastest, private implementation of the technology at the time of the conference [1].

This year Sandia elected:

- to demonstrate how SMDS technology, performance, and functionality have matured (particularly as a "bridging technology"),
- to feature early successes in interoperating a variety of ATM switches and UDP/TCP/IP based applications [7],
- to highlight the utility of innovative application of SONET as a "virtual pipe" technology to deliver high quality voice, data, and video [5].

This paper describes and documents these efforts and the resulting accomplishments. The next three sections describe the three distinct wide area networks. The SMDS extension is described next (see section 2), followed by the ATM/SONET network extension (see section 3), and finally by the HIPPI/SONET network (see section 4).

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¹T. J. Pratt and Steven A. Gossage, Sandia National Laboratories, Department 1954, played instrumental roles in designing and building 1993's *SCInet*

2 Building Information Superhighways Today with ATM, SMDS and DS3

Pioneering new technologies to move large amounts of data at high speeds over long distances, Sandia National Laboratories in collaboration with AT&T and U S WEST constructed a high-capacity network which is a forerunner to the kind of "information superhighways" being proposed for the nation's future needs for high-capacity transmission of multimedia data (see Figure 1). Utilizing private SMDS network facilities at Sandia combined with public U S WEST SMDS service in Portland, the longest interexchange Switched Multimegabit Data Service (SMDS) network in existence was constructed. Acting as an "information superhighway", this network linked the advanced supercomputing environments of Sandia National Laboratories (SNL), Los Alamos National Laboratories (LANL), and Lawrence Livermore National Laboratories (LLNL) to the show floor at *Supercomputing '93*.

The unique combination public and private network was fully connected at DS3 (44.736 Mbps) utilizing AT&T BNS-2000 switches located in Sandia's New Mexico and California sites and the U S WEST Portland Central Office (see Figure 2). The AT&T BNS-2000 switches provided connectionless SMDS functionality via ATM cell switching. Sandia's private SMDS network, extending between California and New Mexico over a private DS3 link, was extended to LANL (approximately 90 miles) over a DS3 circuit provided by U S WEST. Similarly, in Livermore, California Sandia's network was extended to LLNL via FDDI. AT&T provided the DS3 interexchange carrier (IEC) circuit to Portland, Oregon from Albuquerque, New Mexico allowing Sandia network access to the US West SMDS facilities in Portland. U S WEST extended the SMDS service to the convention center floor where *SCInet '93* distributed it to the research booths of LANL, LLNL, Oak Ridge National Laboratories (ORNL)², and SNL. Conference attendees could use LAN-attached workstations at the individual booths to access the MPCRL and other computing resources at the National Laboratories including California's Heterogeneous Environment and Testbed (HEAT).

Additionally, the network provided access to the National Information Infrastructure Testbed (NIIT) between Albuquerque, Livermore and the convention show floor [8]. This was the first demonstration of interoperability of ATM and SMDS through independent interexchange (AT&T, Sprint) carriers.

This experimental network demonstrated how, with state of the art telecommunications technologies (ATM, SMDS, SONET), a high performance network

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²lack of the appropriate interface prevented ORNL's use of the network

Figure 1: Sandia's *Supercomputing '93* SMDS/ATM Network

could be implemented over long distances today. The network was capable of measured sustained throughputs of 6 to 8 megabits per second for a single session. Multiple simultaneous sessions are frequently supported up to the limits of the DS3 trunk. These throughputs are dominated by the effects of disk speeds and by the 35 millisecond delays on TCP/IP based communications [17]. In the local environment the network we have measured 29 megabits per second throughput (memory to memory) for a session [16]. The ease of construction and robustness over the duration of the conference highlighted the potential U.S. competitive advantage that the telecommunications infrastructure brings to bear on today's problems. There were no failures or errors in the telecommunications circuits and switches during the network's operation. Over the duration of the conference, the applications generated the traffic tabulated in Table 1³. These numbers are significantly (approximately 89%) less than recorded at *Supercomputing '92* but can be attributed to more self contained demonstrations and the fact that the bandwidth intensive video applications were confined to the OC-3c link [1]. A significant benefit provided by the SMDS network was the ability to utilize the computing environments at SNL, LANL, and LLNL from

³These statistics were gathered and compiled by J. P. Brenkosh, Sandia National Laboratories, Department 1954, using a Starkeeper management system located in Albuquerque, NM

Figure 2: Details of Sandia's Supercomputing '93 SMDS/ATM Network

Portland just as if the computer users were at their own sites.

3 Heterogeneous, Multimedia ATM Networking Over Carrier-Provided SONET OC-3c

Sandia National Laboratories in collaboration with ATM switch partners from AT&T, FORE Systems, Newbridge, and SynOptics and communications partners from AT&T and U S WEST conducted the largest, fastest multimedia experiment of ATM, SONET, Synchronous Digital Hierarchy (SDH) and interoperability in a production telecommunications environment at *Supercomputing '93* (see Figure 3) [9].

This experiment vividly demonstrated the viability of ATM technology over SONET transmission facilities at a data rate of 155.52 megabits per second with

Table 1: Sandia's ATM/SMDS Network Traffic in Megabytes at SC '93

Date	NM to OR	OR to NM
12 Nov. 93	36	7
13 Nov. 93	315	87
14 Nov. 93	6,342	5,623
15 Nov. 93	11,677	6,631
16 Nov. 93	11,921	6,612
17 Nov. 93	3,515	1,841
18 Nov. 93	814	295
Trunk Totals	34,620	21,096
Grand Total	55,716	

real production applications of video, data, and audio. The major goals of the experiment were to establish a benchmark on the status of ATM and SONET by focusing on equipment interoperability, measured performance, and suitability for major scientific and engineering applications [14] [10].

Several significant results were achieved in this experimental venue provided as part of Sandia's participation in *Supercomputing '93*. Among the most important were:

- An eclectic assemblage of ATM switches representing many vendors were interoperated in a heterogeneous network. The switches included: one AT&T/NTT 20 Gbps ATM cross-connect switch, two Newbridge 36150 Mainstreet switches, two Fore Systems ASX100 ForeRunner ATM switches, and two SynOptics LattisCell switches. This interaction required the use of many of the major emerging standards including STM-1 (CCITT "SONET"), OC-3c, AAL3/4, AAL5, permanent virtual circuits (PVC), and switched virtual circuits (SVC).
- The switches located in Albuquerque, New Mexico and Portland, Oregon communicated using SONET multiplexers over 155.52 megabits per second of bandwidth provided by AT&T. U S WEST provided the local exchange carrier (LEC) access in Portland and Albuquerque. The two ATM networks were separated by a distance of 1500 miles. This collaboration dramatically established the maturity and interoperability of the emerging ATM and SONET standards including the mid-span meet of dissimilar SONET OC-3c equipment. OC-12 and OC-48 aggregates were utilized in the LEC extensions to enable the delivery of ATM over the OC-3c pipe. Likewise, it provided an early demonstration and prototype of Information Superhighways of the future.

- UDP based video conferencing over ATM at OC-3c rates was demonstrated with Parallax interface boards running Paradise software in Sun Sparc 10s.

During the show, a number of experiments were constructed and executed. An HP model 75000 ATM/SONET analyzer⁴ was added to the network and was used to generate background traffic loads, to inject data into the network, and to measure different network parameters and characteristics such as cell loss, cell latency and cell latency distribution⁵. Measurement of cell delay in the heterogeneous telecommunications environment provides an early look at parameters required to properly provision production ATM networks [3]. The ATM portion of *SCInet* was added to the network extending the network all the way to The Boeing Company in Seattle, Washington indicating the flexibility and ease of ATM network integration. On the last day of the show an application from a multimedia video server in the Whittaker Communications booth was used to place a sustained 80 megabits per second (UDP) load through *SCInet* and looped through the ATM switches located in Albuquerque. Multimedia video over UDP, use of the Network Network Interface (NNI) and User Network Interface (UNI) specifications, use of both PVC and SVC connections over the combined SONET OC-3c and STM-1 network served to demonstrate the rapidly expanding functionality of ATM in a state-of-the-art telecommunications network [4].

4 Extending HIPPI Networking Over SONET OC-12

Sandia and Los Alamos National Laboratories in collaboration with INTEL, U S WEST, GTE, and AT&T conducted a heterogeneous experiment of HIPPI Networking over SONET OC-12 at *Supercomputing '93* (see Figure 4). This experiment poignantly demonstrated the viability of HIPPI technology over SONET transmission facilities at a data rate of 622.08 megabits per second with real production applications of video and data.

The major goals of the experiment were to establish a benchmark on the status of HIPPI and SONET by focusing on equipment interoperability, measured performance, and suitability for major scientific and engineering applications. A key component in this experiment was a newly developed interface for SONET

⁴Special thanks to Rob Rowlands, Hewlett Packard, for providing the analyzer and for performing the tests.

⁵An Adtek cell generated was provided by CoTera Technologies but time constraints prevented its use

**Heterogeneous, Multimedia ATM
Networking over Carrier Provided SONET OC-3c**

Figure 3: Heterogeneous ATM over OC-3c/STM-1

that was designed by Los Alamos for CASA Gigabit Testbed under sponsorship of DOE, NSF, and ARPA [11]. This component is called the HIPPI/SONET Gateway and is designed to provide HIPPI connections at distances up to 2000 kilometers at full HIPPI rate of 800 megabits/sec by striping delivered bandwidth over multiple OC-3c paths. The SONET link at the show was built for OC-12 (622.08 megabits per second). The other significant component of the experiment was the OC-12 multiplexer provided by AT&T. The OC-12 multiplexer is one of the family of products that AT&T provides for SONET applications.

Sandia has on going projects to deliver SONET capability at both of its sites and was instrumental in designing, installing and coordinating the various aspects of this experiment to show the utility and maturity of the technology. Sandia managed the SONET portion of the system from its New Mexico facility⁶.

LANL engineers⁷ showed computer generated movies modeling the smoke cloud movement over the gulf as a result of the oil field fires in Kuwait during Operation Desert Storm. By adding or removing OC-3c channels from the HIPPI/SONET Gateway connection, it was easy to see the visual effects of variable amounts of bandwidth to the quality of demonstration. Throughputs of 520 megabits per second were measured on this application during the confer-

⁶Joseph H. Maestas and Thomas J. Pratt, Sandia National Laboratories, Department 1954, installed and operated the multiplexing equipment

⁷Wally St. John, Dave Dubois, and their colleagues

Figure 4: HIPPI over SONET OC-12

ence. That is approximately 87 percent of the maximum available user payload of the OC-12 link indicating an excellent conversion efficiency over the latency involved [15].

Several significant results were achieved in the experimental venue provided as part of Sandia's and Los Alamos' participation in *Supercomputing '93*. Among the most important are:

- Establishment of a HIPPI Network separated by a distance in excess of 15 miles over SONET OC-12. This link was established utilizing a prototype HIPPI/SONET Gateway developed by Los Alamos National Laboratories and AT&T DDM-2000 OC-12 Multiplexers. The local dark fiber facilities were provided by U S WEST and GTE to connect an INTEL Paragon MPP computer in Beaverton, Oregon⁸ to the Portland, Oregon convention center.
- The collaboration dramatically established the maturity and interoperability of the HIPPI and SONET standards in a multi-vendor environment. This experiment provides an early demonstration of Gigabit supercom-

⁸the Paragon was never actually used to transfer data over the circuit during the conference

puter networking into a standard SONET national telecommunications infrastructure, the *pavement* of the future "information superhighways."

- Re-emphasized the synergy of standards as a way to implement gigabit connectivity both quickly and pervasively.

The HIPPI/SONET Gateway enabled by a carrier provisioned SONET infrastructure extended the ANSI HIPPI standard (the channel interface of choice by virtually all supercomputer vendors) well beyond the local machine room and into the gigabit network cloud of the future.

5 Lessons Learned

A number of lessons were learned along the way to implementing these networks. The most important included:

- forming mutually advantageous partnerships to feature advanced capabilities must be done well in advance of the first *SCInet* meetings,
- a well developed plan should be presented at the first *SCInet* meeting with all key partners present,
- the temptation to modify and expand the plan should be avoided as the conference draws near,
- be sure to include in the early planning stages all Sandia departments that will be impacted so that they can schedule necessary activities and upgrades as early as possible.

The partnerships with AT&T, U S WEST, Intel, LANL, and LLNL were initiated in January, 1993. Likewise, the intersite communications group, Department 1955, took the initiative to provide the necessary SONET bandwidth and connectivity when they first heard of evolving plans for *Supercomputing '93*. The work of the advanced team⁹ in Portland two weeks prior to the opening of the conference was critical to the success of the Sandia demonstrations.

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⁹The advanced team included Nicholas Testi, Joseph Maestas, Joseph Brenkosh, and Thomas Pratt, Sandia National Laboratories, Department 1954.

6 Conclusion

By all measures the conference proved successful for Sandia. The conference provided a forum for Sandia to feature a wide variety of state-of-the-art networking and communications technologies and associated applications. The demonstrations benchmarked the current state of the SONET and ATM technologies, both of importance to many Sandia initiatives. The success stories were the culmination of work accomplished by many Sandia departments and their industrial and academic partners. In order to meet the challenging goals of the state-of-the-art networks, many teams were formed that crossed corporate and organizational boundaries. The teamwork amplified the accomplishments and achievements of all the participants. Similarly, the conference provided many Sandians an individual opportunity for professional growth, friendly competition, and professional association. Still, on another level, the conference challenged its participants to take stock of their individual projects and to focus them for the demonstration. In all these ways, Sandia benefitted from its participation in *Supercomputing '93*.

7 Acknowledgements

The networks built for *Supercomputing '93* involved the work of many individuals working together as a team. The following individuals played major roles: Thomas Pratt (overall coordination and network construction); Joseph Maestas and Dave Tapscott (SONET distribution); Joseph Brenkosh (SMDS network and Starkeeper configuration); Bruce Whittet, Richard Gay and Luis Martinez (LAN and router configuration and network management); Nick Testi, John Naegle, Tom Tarman, and John Zepper (ATM network and multimedia demonstration); and Ivory Alexander, Frank Castelluccio, and George Yonek (intersite circuits). Oscar Suarez¹⁰, Linda Thue¹¹, Richard Krajcik¹², Robert Breen¹³, Mark Wilcop¹⁴, Doug Taylor¹⁵, Kristie Wegman¹⁶, and Karen Tincher¹⁷ were instrumental in mobilizing their individual corporations in supporting the construction of Sandia's networks. Mark Bordogna¹⁸, Charles Crue¹⁹ and Chen

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¹⁰AT&T

¹¹AT&T

¹²AT&T

¹³AT&T

¹⁴U S WEST

¹⁵U S WEST

¹⁶U S WEST

¹⁷SynOptics

¹⁸AT&T

¹⁹AT&T

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