Research and Development of High-End Computer Networks at GSFC

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Abstract - **Users of computer networks do not always get the throughput performance that they should get or need to get. Various factors affect the throughput performance, including bandwidth limitations in some links in the end-to-end network path between the user's client workstation and the server and limitations in the throughput performance of the hardware/ software network interface of the client workstation or server. Recent objectives of GSFC's high-end computer networking research and development are to research, evaluate, demonstrate, and provide new, minimum-cost network technologies that: 1) increase bandwidth to a non-blocking capability in the network links at GSFC and in GSFC's links with various research-oriented wide area networks, and 2) provide pro-active measures of throughput performance to identify the cause of individual users' throughput performance limitations and provide network performance assistance to optimize the network interfaces and paths used by those network users.**

I. Introduction

NASA's Earth Science program has ever-increasing requirements for high-end computing, mass data storage, and scientific visualization, all supported and interconnected by high-performance computer networks. Fortunately, and with some NASA assistance, the computer and data communications-related information technology (IT) industries regularly produce advances in these technology areas, partly keeping pace with the application requirements. Unfortunately, many of these same technologies have become complex to use, and typically require a cadre of experts to enable their most effective use either individually or in combination as multi-functional integrated systems. From among the aforementioned technologies, this paper focuses on some successes in large-scale field tests and use of several advanced and high-speed networking technologies to implement more effective high-performance computer networks, used in conjunction with the other computer-related technologies, to advance NASA's Earth Science program.

A. GSFC HECN Project

Users of computer networks do not always get the throughput performance that they should get or need to get. Various factors affect the throughput performance, including bandwidth limitations in some links in the end-to-end network path between the user's client workstation and the server and limitations in the throughput performance of the hardware/ software network interface of the client workstation or server. To address some of these problems, a High-End Computer Network (HECN) Project was created within the NASA Goddard Space Flight Center's (GSFC's) Earth and Space Data Computing Division, receiving annual support from the Earth Science Technology Office (ESTO) Computational Technologies (CT) Project [1] (formerly the High-Performance Computing and Communications (HPCC) Earth and Space Sciences (ESS) Project) and other sources. The network engineering team members associated with the HECN Project repeatedly have applied themselves both to evaluating many new advanced networking technologies to understand how they can be installed and configured to achieve maximum data transfer performance and to deploying those technologies in large-scale field tests, pilot demonstrations, and pre-institutionally supported situations that benefit various Earth science application projects that particularly need high data transfer rates.

Pre-2000 HECN Project efforts included evaluations of 622 megabit per second (Mbps) and 2.4 gigabit per second (Gbps) Asynchronous Transfer Mode (ATM) technologies and transport layer protocol enhancements in several large-scale research network field tests involving both multi-wavelength optical fibers and geosynchronous communications satellites (GEOCOMMSAT's) [2] [3]. More recently, the HECN Project's attention has been drawn to evaluating and applying 1 Gbps and 10 Gbps Gigabit Ethernet (GigE) technologies over optical fiber networks to support Earth science applications involving real-time data capture/analyses and storage area networks (SAN's) extended over Internet Protocol (IP)-based networks.

The present objectives of GSFC's HECN research and development in support of the ESTO CT Project are to research, evaluate, demonstrate, and provide new, minimum-cost network technologies that: 1) increase bandwidth to a non-blocking capability in the network links at GSFC and in GSFC's links with various research oriented wide area networks, and 2) provide pro-active measures of throughput performance to identify the cause of individual users' throughput performance limitations and provide network performance assistance to optimize the network interfaces and paths used by those network users.

This paper provides a brief summary of some recent HECN Project accomplishments and a brief introduction to some on-going HECN Project efforts undertaken to meet its present objectives.

II. Motivation: Example Requirements

The need for high-performance computer networks is driven by many factors. One factor is the coupled relationship that is associated with interests in ever higher-end computing. This relationship depends significantly on the computing applications, but a pertinent set of examples has been compiled from data obtained from the ESS Round 2 Science Team of Grand Challenge Investigators. These Investigators identified that, as they planned to use more processing speed to run higher-resolution models, they would need to move larger amounts of data from the central computer(s) to their local environments. A graph of that data illustrating the quantitative relationship between network and processing requirements is provided in Fig. 1.

Other factors and more general requirements include interest in saving both time and money in backing up data storage remotely as the speed of computer network technology increases and its cost of deployment and operation decrease. For example, considerably more interest has arisen in backing up SAN's now that 1 to 10 Gbps GigE-based networks match and surpass the 1 to 2 Gbps speeds of today's Fibre Channel-based SAN's, with a GSFC-specific example discussed below.

III. Nuttcp

Many of the network technologies, HECN Project accomplishments, and HECN Project on-going efforts described below are characterized by the metric of throughput performance measured as the amount of user-provided "payload" data (in bits) transferred over the network in a time interval (in seconds). This metric intentionally does not count the "overhead" header and trailer bits that are successively added by the next lower layer of stacked protocols, which packetize the user payload before transmitting it over the network. Due both to the number of overhead bits that can be added and to any non-transmission wait times required by either the higher layer protocols or the physical layer components of the networking technologies used in the various parts of the end-to-end network between a user's source and destination, the measure of throughput performance may be very different from the raw "wire speed" of the network equipment. But from a network user's point of view, the measure of throughput performance is most pertinent.

Recognizing the importance both to network users and to network engineers and troubleshooters of being able to easily measure throughput performance, GSFC's Bill Fink developed the software-based nuttcp [4] throughput performance measurement tool. Nuttcp provides many significant enhancements and adds many new optional features to the more basic capabilities of the previously existing nttcp and ttcp tools [5].

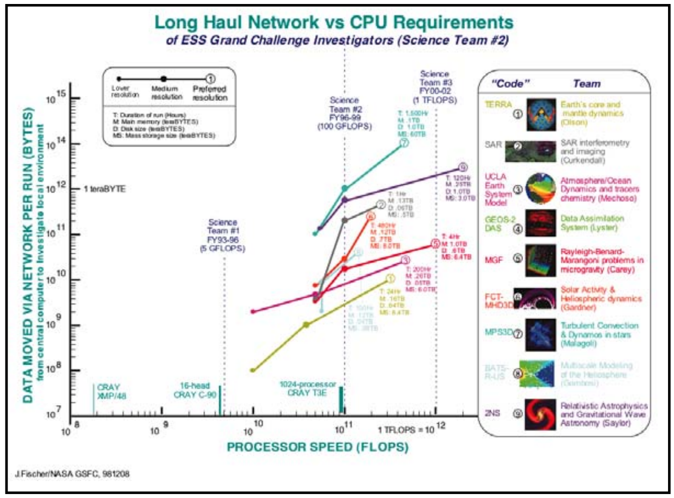


Fig. 1. Example relationship between network and processing requirements.

Nuttcp is a network performance measurement tool intended for use by network and system managers. Its most basic usage is to determine the raw Transport Control Protocol (TCP) (or User Datagram Protocol (UDP)) network layer throughput by transferring memory buffers from a source system across an interconnecting network to a destination system, either transferring a specified number of buffers or alternatively transferring data for a specified time interval. In addition to reporting the achieved network throughput in Mbps, nuttcp also provides additional information related to the data transfer such as user, system, and wall-clock time; transmitter and receiver CPU utilization; and loss percentage (for UDP transfers). The set of options selectable when using nuttcp as a source (transmitter) system is shown in Fig. 2. A near matching set of options is selectable when using nuttcp as a destination (receiver) system; and additional options are available for when nuttcp is used in server mode.

```
Usage (transmitter): nuttcp -t [-options] host [ <in ]
    -l##    length of network write buf (default 8192/udp, 65536/tcp)
    -s      don't source a pattern to network, use stdin
    -n##    number of source bufs written to network (default 2048)
    -w##    transmitter window size in KB
    -ws##   server receive window size in KB
    -wb     braindead Solaris 2.8 (sets both xmit and rcv windows)
    -p##    port number to send to (default 5001)
    -P##    port number for control connection (default 5000)
    -u      use UDP instead of TCP
    -D      don't buffer TCP writes (sets TCP_NODELAY socket option)
    -N##    number of streams (starting at port number)
    -R##    transmit rate limit in Kbps (or (m|M)bps or (g|G)bps)
    -T##    transmit timeout interval in seconds (or (m|M)inutes)
    -i##    server interval reporting in seconds (or (m|M)inutes)
    -Ixxx   identifier for nuttcp output (max of 40 characters)
    -F      flip option to reverse direction of data connection open
    -xP##   set nuttcp process priority (must be root)
    -d      set TCP SO_DEBUG option on data socket
    -v      verbose output
    -b      brief output
```

Fig. 2. Options selectable when nuttcp used as a source (transmitter) system.

Nuttcp is considered a significant product of the HECN Project because of its recognition and use both outside and inside the HECN Project. For example, nuttcp received recognition in the SC2002 conference's High Performance Networking Tutorial instructional material [6], where it is listed as the recommended "great successor" to ttcp and example outputs from nuttcp use are presented. In addition, the Defense Research and Education Network is now using nuttcp for routine performance monitoring of its network. The HECN Project itself uses nuttcp routinely as its prime tool for assessing the effective performance of the networking technologies it evaluates or otherwise uses. Hence, in all following sections of this paper, when references are made to measures of throughput performance, those measures were collected with nuttcp (unless explicitly stated otherwise).

IV. Completed Throughput Performance Evaluations

Several significant advanced network technologies in large-scale research network field tests have been evaluated by the HECN Project with the nuttcp throughput performance measurement tool. This section highlights several findings.

A. 622 Mbps/OC-12c and 2.4 Gbps/OC-48c ATM in ATDnet

The Advanced Technology Demonstration Network (ATDnet) is a high-performance networking testbed in the Washington, DC area intended to be representative of possible future Metropolitan Area Networks [7]. ATDnet has a primary goal to serve as an experimental platform for diverse network research and demonstration initiatives. Recent emphasis has included early deployment of optical networking technologies such as cross-connects and wave division multiplexing (WDM) add/drop multiplexers (A/DM), ATM, Synchronous Optical Network (SONET), Packet over SONET (POS), and progressive scan High Definition Television (HDTV).

The HECN Project's lab at GSFC has served as a core node on the dual 2.4 Gbps/OC-48c ATM backbone ring interconnecting with other core nodes at (clockwise from GSFC) Naval Research Laboratory (NRL), Defense Information Agency (DIA), Defense Information Systems Agency (DISA), Defense Advanced Research Projects Agency (DARPA), and National Security Agency (NSA). Each core node includes a FORE ASX-4000 ATM switch with dual port 2.4 Gbps/OC-48c ATM modules plus various other edge ATM switches and edge user workstations connected to the core node with 622 Mbps /OC-12c modules and network interface cards (NIC's).

One particular HECN-conducted nuttcp-based evaluation involved transmitting 1 terabyte of data between a Sun UltraSPARC-2/300 with a 622 Mbps /OC-12c NIC connection to the ATDnet at GSFC and an identical workstation at NRL. With the Maximum Transmission Unit parameter configured to 9180 bytes and TCP's window size adjusted optimally for the round trip time, Bill Fink measured the throughput performance at 416 Mbps with the transmit and receive workstations' processors at 77% and 85% utilization, respectively. That test was conducted on 3 March 1998, when the cost of those workstations and NIC's was already under $10,000. A diagram identifying the network connections and additional details regarding that test is provided in Fig. 3.

B. 622 Mbps/OC-12c ATM over ACTS

GSFC's Pat Gary was co-Principal Investigator with DARPA's Gary Minden on the Advanced Communications Technology Satellite (ACTS) Project Experiment #118, "622 Mbps Network Tests Between ATDnet and MAGIC Via ACTS" [8], which enabled experiments among workstations connected by the networks shown in Fig. 4. The 540 millisecond round trip time through the ACTS GEOCOMMSAT, coupled with ACTS' high data rate capability to handle three simultaneous full duplex 622 Mbps connections, provided a significant field test opportunity for evaluating the implementations and effects of TCP large window [9] and selective acknowledgments [10] protocol options on various applications. While the ACTS Experiment #118's high-water throughput performance of 520 Mbps memory-to-memory and 320 Mbps aggregate (three streams) tape-to-tape were set by NASA Glenn Research Center-based co-Investigators (co-I's) David Beering (Amoco) and Dave Brooks (Sterling), several other very informative results were produced by Kansas University-based investigators under co-I Victor Frost [11].

C. 155 Mbps/OC-3c ATM through STK/NSG ATLAS Firewall

In addition to the technology evaluations referenced above, the HECN Project also utilized ATDnet and ACTS while

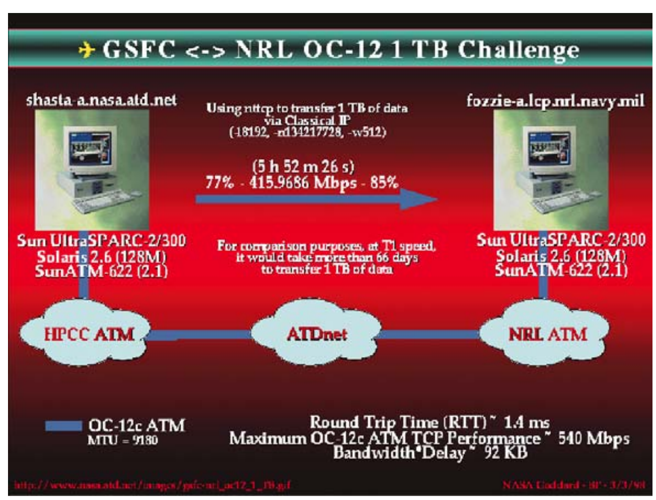


Fig. 3. GSFC <-> NRL OC-12c 1 Terabyte Challenge.

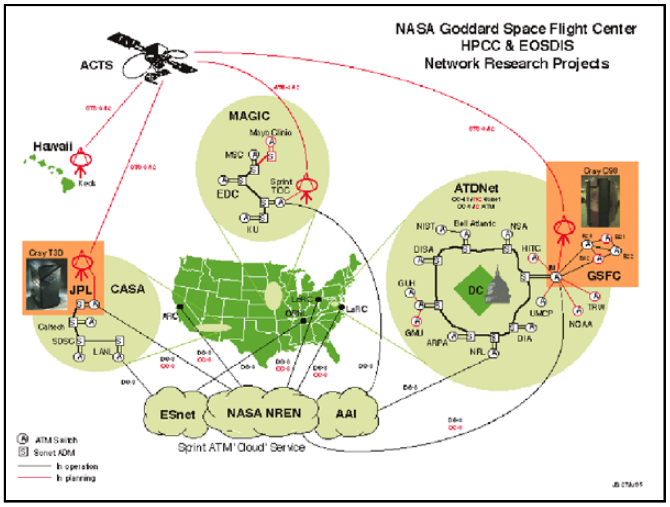


Fig. 4. Research network connections via ACTS evaluated by HECN Project.

conducting throughput performance evaluations of the STK/NSG ATM Line Access and Security System (ATLAS) ATM firewall device. In these tests, the HECN Project served as the leading participant in the NSA-sponsored Security Proof of Concept Keystone (SPOCK) initiative to validate selective capabilities of the STK/NSG ATLAS ATM firewall [12]. The network configuration used during those tests is shown in Fig. 5; key findings from those tests are available at [13]. Additional evaluations conducted with ACTS by the HECN Project are provided in [14] and [15].

D. 100 Mbps SkyX Gateway through Simulated GEOCOMMSAT

During the ACTS-based tests, the HECN Project came to more fully understand the importance that TCP's congestion avoidance algorithm can have in high bandwidth*delay networks with even very small bit error rates (BER's).

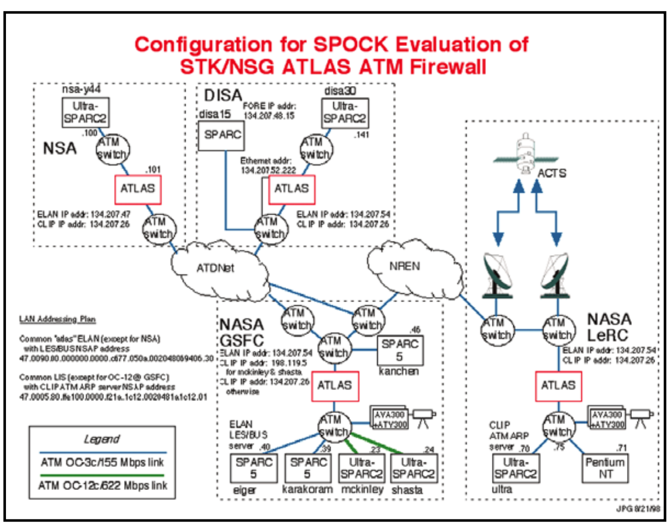


Fig. 5. Network configuration for SPOCK evaluation of ATLAS ATM firewall.

To determine how to mitigate or avoid this problem in other high bandwidth*delay networks with links through GEOCOMMSAT's, the HECN Project evaluated Mentat's SkyX Gateway product in a 100 Mbps network link involving a simulated GEOCOMMSAT and varying BER conditions. We knew that the SkyX Gateway would replace TCP in the GEOCOMMSAT link between the SkyX Gateways, but we found the SkyX Gateway's TCP spoofing to be totally transparent to all our nuttcp and other application-oriented tests. Moreover, SkyX Gateways improved the end-to-end performance in all BER conditions we tested, including some wherein TCP connections were no longer possible. A representative set of our findings is provided in Fig. 6.
The above findings came to the attention of GSFC's Tracking and Data Relay Satellite (TDRSS) Project, which subsequently deployed SkyX Gateways in the South Pole TDRSS Relay Internet Protocol link.

E. 100 Mbps SkyX Gateway through Two GEOCOMMSAT's During TPD

The Trans-Pacific Demonstration (TPD) was planned as a significant experiment of the G7 Information Society's Global Interoperability for Broadband Networks Project [16]. A diagram illustrating the initially planned configuration of networks to support the TPD is shown is Fig. 7. The final TPD simultaneously enabled two Internet-based interactive application demonstrations. In a demonstration involving interactive access to the Visible Human data set at the National Library of Medicine from the Sapporo Medical Center in Japan, the 20 Mbps end-to-end network link included not only one 155 Mbps/OC-3c link through an Intelsat GEOCOMMSAT but also a second 155 Mbps/OC-3c link through the NSTAR GEOCOMMSAT managed by Japan's Communications Research Laboratory.

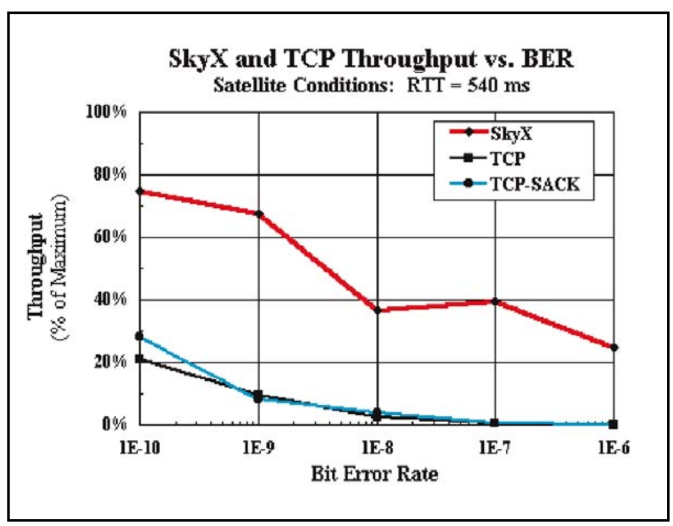


Fig. 6. SkyX and TCP throughput versus BER.

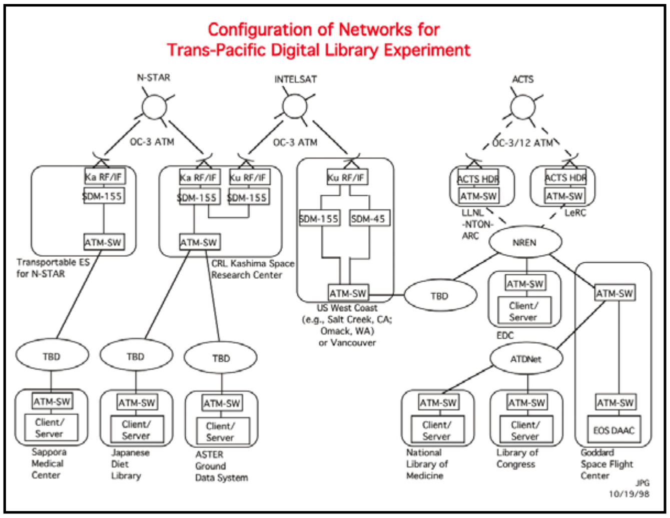
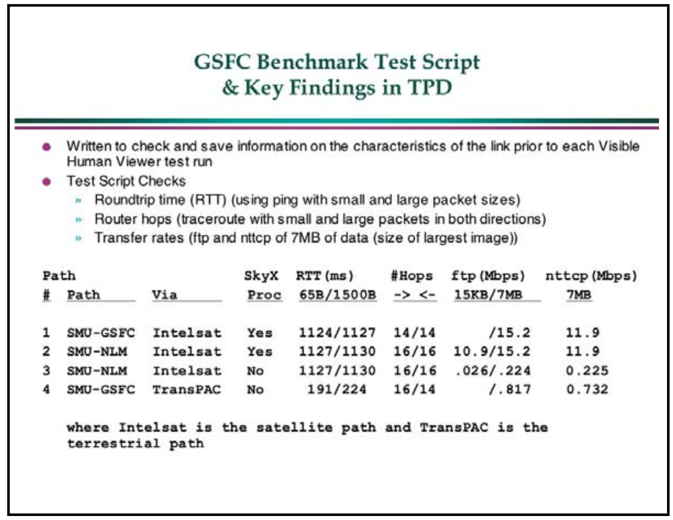


Fig. 7. Initially planned configuration of networks to support the TPD.


GSFC Benchmark Test Script
& Key Findings in TPD

- Written to check and save information on the characteristics of the link prior to each Visible Human Viewer test run
- Test Script Checks
  - Roundtrip time (RTT) (using ping with small and large packet sizes)
  - Router hops (traceroute with small and large packets in both directions)
  - Transfer rates (ftp and nttcp of 7MB of data (size of largest image))

Path #	Path	Via	SkyX Proc	RTT (ms) 65B/1500B	#Hops -> <-	ftp (Mbps) 15KB/7MB	nttcp (Mbps) 7MB
1	SMU-GSFC	Intelsat	Yes	1124/1127	14/14	/15.2	11.9
2	SMU-NLM	Intelsat	Yes	1127/1130	16/16	10.9/15.2	11.9
3	SMU-NLM	Intelsat	No	1127/1130	16/16	.026/.224	0.225
4	SMU-GSFC	TransPAC	No	191/224	16/14	/.817	0.732

where Intelsat is the satellite path and TransPAC is the terrestrial path

Fig. 8. Throughput performances of TPD's different network configurations.

When it was finally determined that the static TCP window sizes in Apple's beta Mac OS X workstations planned for use in Sapporo could not be changed within the time or funding constraints of the TPD, loaner SkyX Gateways were deployed on both sides of the two GEOCOMMSAT end-to-end link.

Nuttcp and ftp throughput performance tests with 7 megabyte images were conducted end-to-end over the two GEOCOMMSAT link (with and without the SkyX Gateways in place) and a 1.5 Mbps terrestrial link involving the Asian Pacific Academic Network. One significant finding was that the throughput performance of the two GEOCOMMSAT links with the SkyX Gateways enabled was approximately 15 Mbps, or more than 65 times the throughput performance of this same link without the SkyX Gateways in place. A summary of the actual findings is provided in Fig. 8. More complete information about the TPD is available in [17].

F. Up to 10 Gbps Multi-Protocol Stack Testing in MONET-Upgraded ATDnet

When the DARPA-funded Multi-wavelength Optical Network (MONET) Program [18] [19] upgraded ATDnet's core network infrastructure to include multi-wavelength optical switching components, the ATDnet core node in the HECN Project's lab was upgraded to include an optical A/DM from Lucent. The A/DM connected eight wavelengths to the optical cross connects at NRL and NSA, with each wavelength capable of handling format transparent data at rates up to 10 Gbps. Fig. 9 contains a diagram identifying the connection topology and the switching components of the east (with Lucent equipment) and west (with Tellium equipment) rings of the MONET-upgraded ATDnet; the figure also shows additional high-performance network links connecting the HECN lab at GSFC with several Next Generation Internet (NGI) networks.

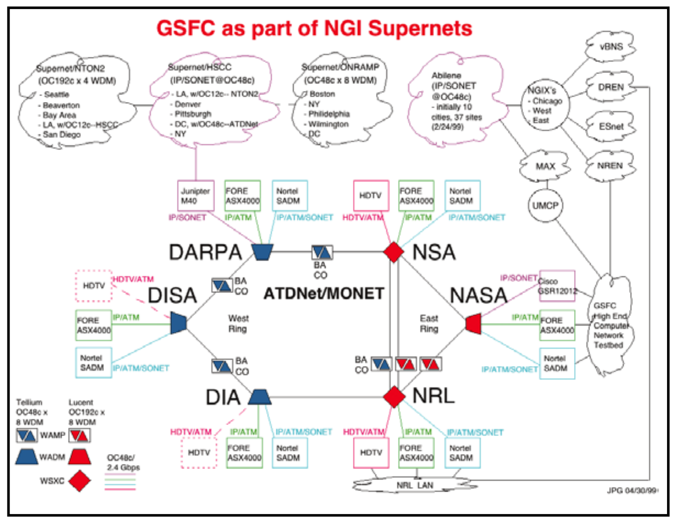


Fig. 9. MONET-upgraded ATDnet configuration with NGI connections.

In the upgraded multi-wavelength configuration, the ATDnet's previous single 2.4 Gbps/OC-48c ATM network now was carried in one of the MONET wavelengths; and the other wavelengths were opened to experimentation with different network protocol stacks. For example, GSFC and DARPA evaluated IP POS networking in one wavelength, while NRL and NSA simultaneously experimented with digitized HDTV carried in ATM cells in a different wavelength. Fig. 10. shows a partial list of the various protocol stacks evaluated for functionality and throughput performance.

Findings from an evaluation of the limits of 1 GigE transmission distance that could be achieved before dispersion effects prohibited an accurate regeneration of the signal are provided in [20]. A summary report highlighting the key findings from the entire MONET Program effort is provided in [21].

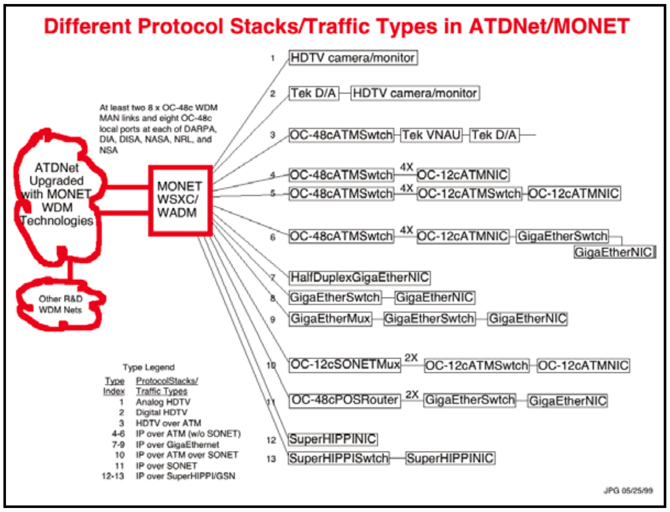


Fig. 10. Different protocol stacks evaluated in ATDnet/MONET.

V. New on-going Advanced Network Technology Deployments and Evaluations

A. Up to 100 Gbps Optical Network Evaluations Planned for ATDnet2

With the 10 Gbps per wavelength goals of the MONET Program met and its first-of-a-kind optical switches now more than five years old, the ATDnet community contracted with the Mid-Atlantic Crossroads Consortium (MAX) to provide better-quality fibers in a new ring topology. These fibers will support new ATDnet2 objectives, which include research and evaluation of new optical networking technologies that can support up to 100 Gbps in each of multiple wavelengths [22]. A diagram illustrating ATDnet2's planned and now nearly complete new ring topology with its core and ancillary sites is provided in Fig. 11.

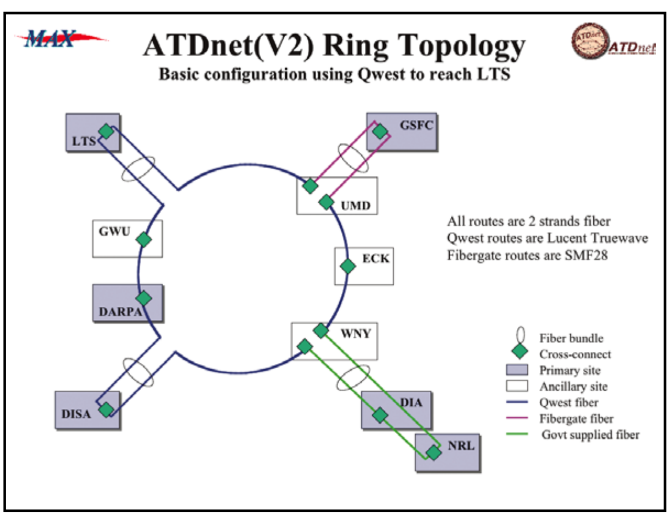


Fig. 11. ATDnet2 Ring Topology.

B. CASPR

While the Lucent optical A/DM equipment recently was removed from the HECN lab to back fill other failed components in the MONET-upgraded ATDnet, the knowledge gained continues to be leveraged as GSFC's Pat Gary is the primary NASA point of contact for four separate optical network research efforts at the University of Maryland Baltimore County's new NASA-funded Center for Advanced Studies in Photonics Research (CASPR) [23].

C. E-VLBI

Earth Science's Very Long Baseline Interferometry (VLBI) project is benefiting significantly from the knowledge and contacts gained from the HECN Project's earlier completed efforts via the e-VLBI. This project has the goal of improving the science value of the data it collects while decreasing the time and cost of handling the data it collects by, e.g., transmitting in real time at 1 Gbps VLBI data acquired from antennas at Westford, MA, and the Goddard Geophysical and Astronomical Observatory (GGAO) in Greenbelt, MD, to a correlator at the MIT Haystack Observatory in MA, as described in the Gbps e-VLBI Demonstration Project [24].

For the e-VLBI data flows across the approximate 650 km end-to-end network path from the GGAO to Haystack, the data traverses:

- a dedicated fiber link between the GGAO and the HECN lab;
- a shared 1 Gbps GigE link in a course WDM wavelength between the HECN lab and the MAX point of presence (POP) at College Park, MD;
- a shared 2.4 Gbps POS link in a dense WDM wavelength between the MAX POP at College Park and the MAX POP in Arlington, VA [25];
- a shared 1 Gbps GigE or 2.4 Gbps POS link in a dense WDM wavelength of the BoSton-South NETwork (BoSSNET) between Arlington and MIT's Lincoln Laboratory (LL) in MA [26]; and
- a dedicated 1 Gbps GigE link in a course WDM wavelength of the Glownet between the LL and the Haystack Observatory [27].

Diagrams illustrating various aspects of the e-VLBI's GGAO-Haystack end-to-end network connection are provided in Fig. 12 and Fig. 13.

Nuttcp throughput performance tests on e-VLBI's GGAO-Haystack end-to-end network have achieved over 970 Mbps in each direction, as confirmed by the mrtg-generated graphs in Fig. 14 showing transmitted data rates sustained during a 16-hour-long evaluation test.

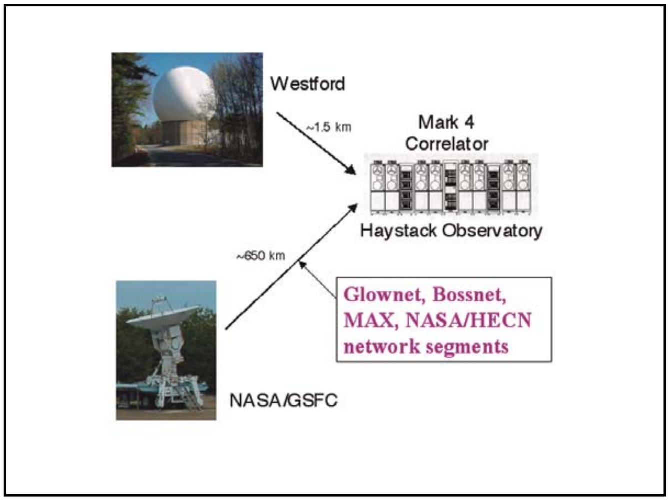


Fig. 12. Schematic of Gbps e-VLBI demonstration experiment.

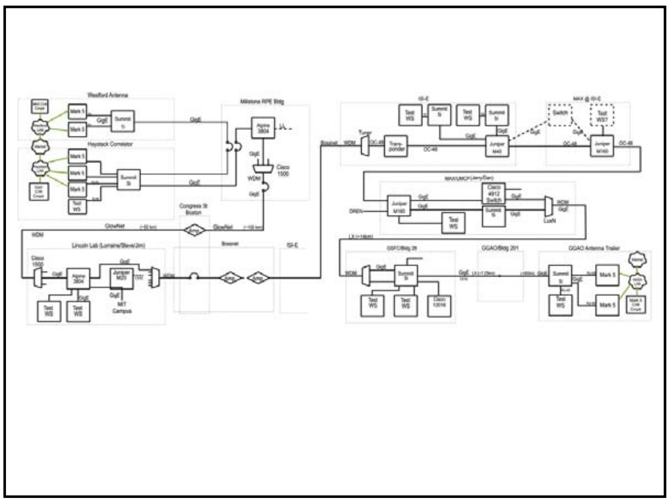


Fig. 13. Details of the e-VLBI network path.

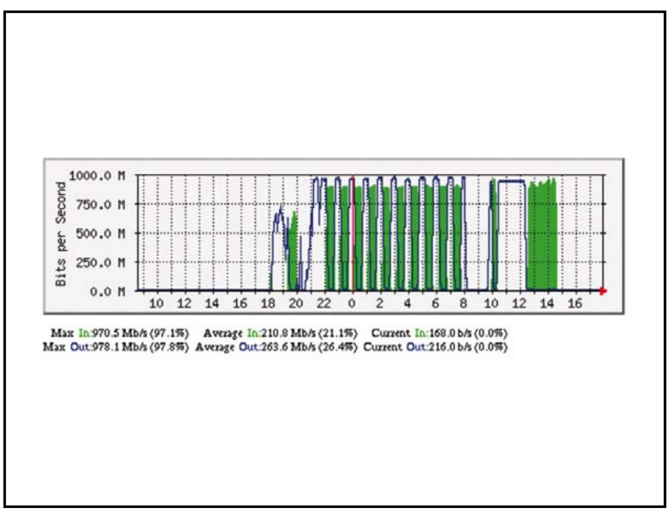


Fig. 14. e-VLBI GGAO-Haystack data rates sustained during a 16-hour-long evaluation test.

D. GSFC SEN Supporting NSIPP

Another Earth Science project benefiting significantly from HECN Project knowledge and deployments of advanced networking technologies is the GSFC-based NASA Seasonal-to-Interannual Prediction Project (NSIPP), which is funding the HECN Project to provide each of 43 user workstations with a 1 Gbps GigE connection to the GSFC Scientific and Engineering Network (SEN). The GSFC SEN is a local, non-mission-oriented, high-end computer network at GSFC with high-speed links to the Internet2's Abilene and other NGI networks, serving GSFC projects/users who have computer network performance capability requirements greater than those baselined for GSFC's more broadly oriented Center Network Environment (CNE).

As a task under the ESTO CT Project, the HECN Project has upgraded the majority of SEN's inter-building backbone links to 2 Gbps via link aggregation of two formerly separate 1 Gbps GigE connections between respective pairs of GigE switches. This upgrade mitigates potential increases in SEN congestion that would be likely on the inter-building backbone links of the SEN's previous architecture (which was based on 622 Mbps/OC-12c ATM links across GSFC's Core ATM Network). Furthermore, the HECN Project has selected jumbo frame-capable GigE switches to implement the SEN's new inter-building backbone links.

The jumbo frame-capable aspects of SEN's new inter-building backbone links should provide individual users with approximately three times better throughput performance as compared to the 300 Mbps they typically achieved over the former inter-building backbone. Furthermore, the additional bandwidth in the SEN's new inter-building backbone links should allow twice as many of those users from twice as many buildings to use their full throughput performance before those links show any signs of congestion. Hence, the combination of more inter-building bandwidth and jumbo frame-capable connections should provide NSIPP users with about 12 times the SEN's former inter-building throughput performance.

E. GSFC SEN Supporting SAN-over-IP

The last Earth Science effort significantly benefiting from the HECN Project to be described in this paper is GSFC's center-wide SAN Pilot Initiative. GSFC's SAN Pilot initially only enabled a 1 Gbps Fibre Channel-based SAN involving three GSFC buildings. With assistance from the HECN Project, the SAN Pilot expanded to include evaluations and support of SAN-over-IP technologies, such as implementations of the Internet Small Computer Serial Interface (iSCSI) protocol, both in iSCSI-routers connected between Fibre Channel-based SAN's and GigE-based networks and in driver software that works in conjunction with a workstation's normal TCP/IP stack. The HECN also provided a jumbo frame-capable 1 Gbps GigE iSCSI-router connection between the SEN and the SAN Pilot's 1 Gbps Fibre Channel-based SAN. A diagram illustrating the SEN's iSCSI-based SAN-over-IP connection with the GSFC SAN Pilot is provided in Fig. 15.

Now, with appropriate authorization and essentially no extra cost, nearly any workstation with a 1 Gbps GigE connection to the SEN can gain full SAN-like block level access to the SAN Pilot's disks; and the throughput performance of that access will be as much as about one-half of the approximate 320 Mbps read or write access performance that the workstation would get if it were interfaced directly to the Fibre Channel of the SAN via a host bus adaptor, which typically costs about $2,000.

SAN-over-IP technologies also are not bound by the maximum 11 km distance specification of Fibre Channel. Working with the SAN Pilot, the HECN Project arranged a GSFC SAN access test from an iSCSI-enabled workstation more than 11 km away from GSFC at the University of Maryland Institute of Advanced Computer Systems, using the previously described 1 Gbps link between GSFC and the MAX POP at College Park. Similar to workstations within GSFC, this workstation also obtained approximately 160 Mbps read and write performance when accessing the disks of the GSFC SAN.

The SEN's jumbo frame capability has been critical to achieving the notable iSCSI-based access performances described above. Specific tests arranged by Bill Fink identify that between a high-end workstation and a high-end network-attached storage device, each with a 1 Gbps GigE connection to the same GigE switch, read and write performance can improve by approximately eight times when the storage device, workstation, and network switch are all configured to support 9000-byte jumbo frames rather than standard 1500-byte frames. The specifics of the test are provided in Fig. 16.

Additional information on the evaluations and findings of the GSFC SAN Pilot are provided in [28].

VI. Conclusion

The emergence of relatively inexpensive 1 and 10 Gbps GigE and WDM optical networking technologies can significantly enable Earth science applications to meet their ever-increasing requirements for higher throughput performance. But knowledgeable selection and use of those technologies can only be achieved through advanced network technology evaluations of the type described in this paper conducted by GSFC's HECN Project.

Acknowledgment

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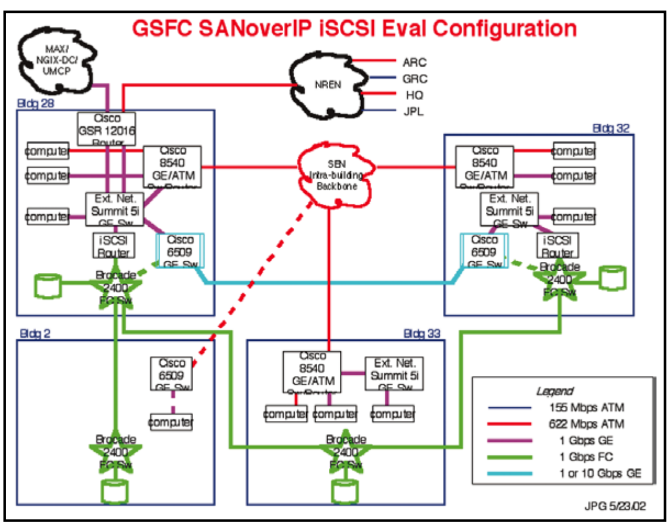

Fig. 15. iSCSI-based SEN connection with the GSFC SAN Pilot.

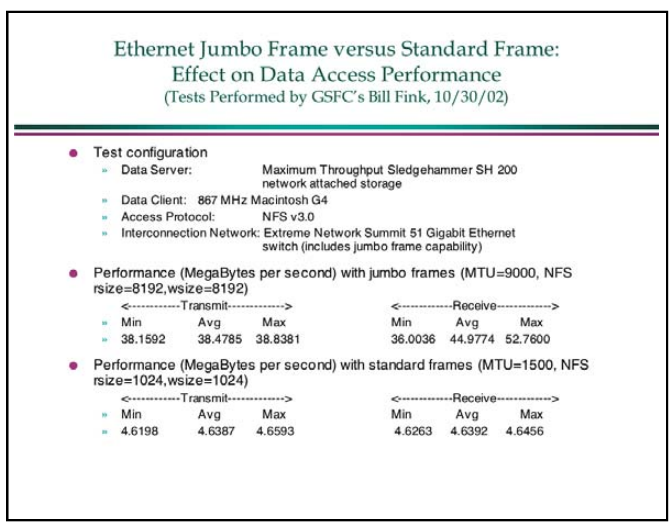

Fig. 16. Ethernet jumbo frame versus standard frame effect on data access performance.

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