INTEGRATION OF THE WHITE SANDS COMPLEX INTO A WIDE NETWORK

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INTEGRATION OF THE WHITE SANDS COMPLEX
INTO A WIDE AREA NETWORK

BY

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A Technical Project Report
in partial fulfillment of the requirements
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ABSTRACT

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BY

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Las Cruces, New Mexico, 1996
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The NASA White Sands Complex (WSC) satellite communications facility consists of two main ground stations, an auxiliary ground station, a technical support facility, and a power plant building located on White Sands Missile Range. When constructed, terrestrial communication access to these facilities was limited to copper telephone circuits. There was no local or wide area communications network capability. This project incorporated a baseband local area network (LAN) topology at WSC and connected it to NASA's wide area network using the Program Support Communications Network-Internet (PSCN-I).

A campus-style LAN is configured in conformance with the International Standards Organization (ISO) Open Systems Interconnect (ISO) model. Ethernet provides the physical and data link layers. Transmission Control Protocol and Internet Protocol (TCP/IP) are used for the network and transport layers. The session, presentation, and application layers employ commercial software packages.

Copper-based Ethernet collision domains are constructed in each of the primary facilities and these are interconnected by routers over optical fiber links. The network and each of its collision domains are shown to meet IEEE technical configuration guidelines. The optical fiber links are analyzed for the optical power budget and bandwidth allocation and are found to provide sufficient margin for this application.

Personal computers and work stations attached to the LAN communicate with and apply a wide variety of local and remote administrative software tools. The Internet connection provides wide area network (WAN) electronic access to other NASA centers and the world wide web (WWW). The WSC network reduces and simplifies the administrative workload while providing enhanced and advanced inter-communications capabilities among White Sands Complex departments and with other NASA centers.

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LIST OF ABBREVIATIONS

10BASE2	Specification for thin coaxial cable Ethernet segments
10BASE5	Specification for thick coaxial cable Ethernet segments
10BASE-F	Specification for fiber optic Ethernet segments
10BASE-FB	Specification for synchronous signaling fiber optic backbone
10BASE-FL	Specification for fiber optic inter-repeater link
10BASE-FP	Specification for a passive fiber optic mixing segment
10BASE-T	Specification for unshielded twisted-pair cable Ethernet segments
100BASE-T	Specification for 100 Mbps UTP Ethernet
APD	Avalanche photodiode
ANS	American National Standards
ANSI	American National Standards Institute
ARPANET	Advanced Research Projects Agency Network
AT&T	American Telephone and Telegraph
ATM	Asynchronous transport mode
ATSC	Allied Technical Services Corporation
AUI	Attachment unit interface
AWG	Average wire gauge
B	Byte (eight bits)
BASE	Baseband modulation, used in Ethernet transmission
BDA	Bermuda (NASA space network ground station call sign)

LIST OF ABBREVIATIONS (CONTINUED)

bps	Bits per second
BL	Blue (a wire color in 10BASE-T connector wiring)
BNC	Name of a bayonet twist-lock coaxial connector
BR	Brown (a wire color in 10BASE-T connector wiring)
BSD	Berkeley software distribution
C	Connector (used to refer to an ST® optical connector)
cm	Centimeter
CSMA/CD	Carrier-sense multiple access with collision detection
CSU	Customer service unit, a demarcation point between the telecommunication carrier's network equipment and the customer's premise equipment
dB	Decibel
dBm	Decibel referenced to one milliwatt
DEC	Digital Equipment Corporation
DIX	Digital, Intel, and Xerox (refers to the companies that released the first Ethernet specification)
DOS	Disk operating system
DTE	Data terminal equipment
E-1	European telecommunications circuit standard, 2.048 Mbps
EC	Engineering change
EIA	Electronic Industries Association

LIST OF ABBREVIATIONS (CONTINUED)

ELED	Edge light emitting diode
Email	Electronic mail
EOPS	Engineering operations
ETGT	Extended TDRSS Ground Terminal
FDDI	Fiber distributed data interface, a 100 Mbps fiber optic network
FOIRL	Fiber optic inter-repeater link
FOMAU	Fiber optic media access unit
FTS	Federal trunking system
FWHM	Full width half maximum
G	Green (a wire color in 10BASE-T connector wiring)
GCE	Ground control equipment
GHz	Gigahertz (unit of frequency equal to 10^9 cycles per second)
GN	Ground network
GTE	General Telephone Equipment
GSFC	Goddard Space Flight Center
GSTDN	Ground Spacecraft Tracking and Data Network
HEC	Hub expansion cable
HP-UX	Hewlett Packard's version of the UNIX operating system
IBM	International Business Machines
IEEE	Institute of Electrical and Electronics Engineers

LIST OF ABBREVIATIONS (CONTINUED)

IFL	Interfacility link
IP	Internet protocol
ISDN	Integrated services digital network
ISO	International Standards Organization
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
K	Kilo (a multiplier of 10^3)
Kbps	Kilobits per second (a data rate unit equal to 10^3 bits per second)
km	Kilometer (a unit of length equal to 10^3 meters)
LAN	Local area network
LCCO	Las Cruces central office
LED	Light emitting diode
LIMS	Logistics inventory management system
LLC	Logical link control
LOPS	Local operations procedures
μ	micro (multiplier of 10^{-6})
m	meter
M	Mega (multiplier of 10^6)
MAU	Media access unit (called a transceiver in the DIX standard)
MAXIMO	Name of a facilities database and management application

Mbps	Megabits per second (data rate unit equal to 10^6 bits per second)
MDI	Medium dependent interface
MHz	Megahertz (unit of frequency equal to 10^6 cycles per second)
MIL	Merritt Island (NASA space network ground station call sign)
MIL-STD	Military-Standard
MM	Multimode
MSFC	Marshall Space Flight Center
MTS	Maintenance tracking system
NA	Numerical aperture
NASA	National Aeronautics and Space Administration
NASCOM	NASA communications network
NC	Not connected
NEU	Network encryption unit
nF	Nanofarad (unit of capacitance equal to 10^{-9} farads)
NIC	Network interface card
nm	Nanometer (unit of length equal to 10^{-9} meters)
NMSU	New Mexico State University
NRZ	Non return to zero
NSC	Network security center
O	Orange (a wire color in 10BASE-T connector wiring)

LIST OF ABBREVIATIONS (CONTINUED)

OC	Optical Carrier (an set of optical telecommunications transport standards, (OC-1 at 51.840 Mbps to OC-48 at 2488.320 Mbps)
OS	Operating system
OSI	Open system interconnection
P	Pigtail (a short optical fiber jumper cable with an ST® connector on one end and spliced on one end to a bulk fiber, used in an optical splice distribution panel)
PC	Personal computer
PDL	Ponce de León (NASA space network ground station call sign)
PIN	Positive-intrinsic negative
ps	picoseconds (a unit of time equal to 10^{-9} seconds)
PSCN-I	Program Support Communications Network - Internet
RD+	Receive data, positive
RD-	Receive data, return
RISC	Reduced instruction set computer
RG-58A/U	Specification for a 50Ω coaxial cable used for 10BASE2 installations
RJ-45	An eight-pin modular telephone jack
rms	Root-mean-square
RX	Receive (a data transmission)
SOLARIS	Sun Microsystems version of UNIX
SONET	Synchronous optical network

LIST OF ABBREVIATIONS (CONTINUED)

SN	Space network
SM	Singlemode
SMTF	Software maintenance and training facility
SQE	Signal quality error
ST®	AT&T Trademark designation of a fiber optic connector
STGT	Second TDRSS Ground Terminal
T-1	Designation for theT-1 building at the White Sands Ground Terminal,. alternatively, transmission level one (1.544 Mbps asynchronous communications circuit)
T-2	Designation for the main building at STGT
T-3	Designation for the STGT power plant building, alternatively, transmission level three (44.736 Mbps asynchronous communication circuit)
T-4	Designation for the STGT guard shack building
T-16	Designation for the Extended TDRS Ground Terminal building
T-20	Designation for the Technical Support Building
T-21	Designation for the WSGT guard shack building
TCP	Transmission control protocol
TD+	Transmit data, positive
TD-	Transmit data, return
TDRS	Tracking and data relay satellite
TDRSS	Tracking and data relay satellite system

LIST OF ABBREVIATIONS (CONTINUED)

TIA	Telecommunications Industry Association
TSB	Technical Support Building
TX	Transmit (a data signal)
ULTRIX	Digital Equipment Corporation version of UNIX
UNIX	Bell Laboratories name of a computer operating system
UTP	Unshielded twisted-pair
VAX	Virtual address extension (DEC trademark for a line of computers)
W-BL	White-Blue (a wire color in 10BASE-T connector wiring)
W-BN	White-Brown (a wire color in 10BASE-T connector wiring)
W-G	White-Green (a wire color in 10BASE-T connector wiring)
W-O	White-Orange (a wire color in 10BASE-T connector wiring)
WAN	Wide area network
WSC	White Sands Complex
WSGT	White Sands Ground Terminal
WSMR	White Sands Missile Range
WSTF	White Sands Test Facility
WWW	World Wide Web

1. INTRODUCTION

In the early 1970s, the National Aeronautics and Space Administration (NASA) decided to redesign its worldwide satellite communications system, the Ground Spacecraft Tracking and Data Network (GSTDN). Instead of using multiple ground stations around the world for low-orbit spacecraft tracking, telemetry downlinking, and command uplinking, NASA would build a Tracking and Data Relay Satellite System (TDRSS) with one communications complex located at the NASA White Sands Test Facility (WSTF) on the White Sands Missile Range (WSMR).

This concept required the user spacecraft to communicate with geostationary Tracking and Data Relay Satellites (TDRS) that served as relay stations to the ground communications equipment at the White Sands Complex (WSC). A pair of TDRS located on the geostationary satellite belt at about twelve degrees above the east horizon and at about eleven degrees above the west horizon from WSC could view low-orbit satellites for 85% of their entire orbits. This is a great improvement over the 15% coverage previously available from GSTDN.

White Sands was chosen[1] as the location for the communications complex for several reasons: 1) climate, the annual rainfall is low and space-to-ground link disruptions from weather would be minimal, 2) NASA Johnson Space Center's (JSC) White Sands Test Facility (WSTF) could provide power, water and waste-water treatment, medical, fire, and other necessary support facilities, 3) the location was

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[1] The author attended a meeting at WSTF in 1976 where NASA representatives announced selection of WSTF for the location of the TDRSS ground station citing the reasons mentioned in this report.

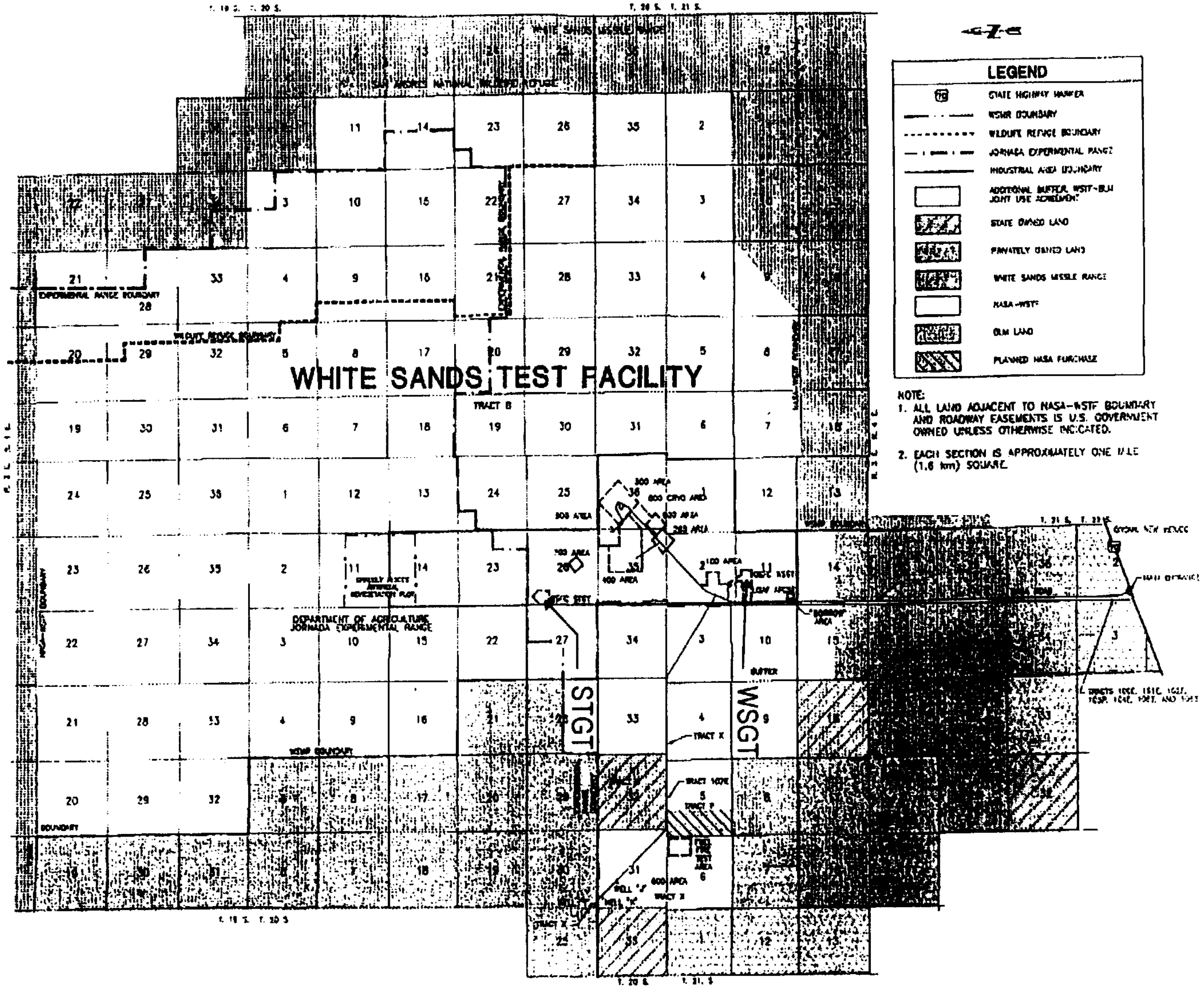
remote and therefore more secure, and 4) the presence of White Sands Missile Range and the strong telecommunications program at New Mexico State University (NMSU) offered access to a well-trained work force.

1.1 Background

The original tracking station, the White Sands Ground Terminal (WSGT), was constructed in 1976 and was provided with copper communications links from US West, the regional Bell operating company. These links were satisfactory for ordinary telephone service and for low-speed computer modem communications to remote facilities; however, they were inadequate for higher data rates.

Personal computers (PCs) were still relatively new in 1976 [1] and connecting them together in a local area network (LAN) or a wide area network (WAN) was still in its infancy. The invention of Ethernet had been reported in July of that year by Metcalfe and Boggs [2] and was used in-house by their employer, Xerox™.

By the middle 1980s, NASA had concerns about the single-point failure represented by the lone TDRSS ground station in its new Space Network (SN). In 1989, a Second TDRS Ground Terminal (STGT) was constructed just three miles north of the original ground terminal. This places STGT outside the beamwidth of the TDRS space-ground link return signal to WSGT. This separation assures that TDRS transmissions intended for one ground station do not interfere with signals intended for the other. Figure 1-1 is a map that shows the relationship of the two ground terminals with respect to White Sands Test Facility and access from US Highway 70.



NOTE:
1. ALL LAND ADJACENT TO NASA-WSTF BOUNDARY AND ROADWAY EASEMENTS IS U.S. GOVERNMENT OWNED UNLESS OTHERWISE INDICATED.
2. EACH SECTION IS APPROXIMATELY ONE MILE (1.6 km) SQUARE.

Figure 1-1

White Sands Test Facility and the White Sands Complex Location

STGT was originally provided with a 300-pair copper cable for communications links to the common carrier's point-of-presence at the White Sands Test Facility, but these were not adequate for high speed communications links. The hardware and software development contractor for STGT wanted to connect their remote computer software development center in Pennsylvania to STGT's computer center with a high speed T-1 telecommunications link, but it was not possible over the 20,000' long copper interface. They eventually connected with a much slower 56 kilo-bit-per-second (Kbps) link. The slower link was marginally usable for the intended task of remote computer program editing. It was not usable for delivering a software update release from the remote host.

STGT was in a position of being a leading-edge satellite communications ground station with high-speed satellite data communications links but hampered with low-speed telecommunications links for telephony and other administrative communications like video teleconferencing and wide area network connectivity.

By the time of STGT activation, there had been many advances in PCs, their operating systems, and in local area networks. The cost/performance ratio of all these items had attained a point where it became not only desirable, but necessary to migrate from paper based administrative systems to electronic based ones. STGT was the first facility at the White Sands Complex to convert to these methods. Because of the success in the administrative LAN application at STGT, the other facilities were also interconnected. It also became desirable to connect via the Internet to the other NASA centers for wide area network services such as Email.

1.2 Purpose

The purpose of this project was to convert the White Sands Complex administrative activities from ones based on paper entries and physical distribution to ones that are computer generated and delivered electronically. While it is not possible, nor desirable, to eliminate paper records entirely, they can become the depository of official and configuration-controlled master and archive documentation rather than being the working papers needed and exchanged daily.

The methodology was to install copper local area networks in each of the principle WSC facilities and then interconnect them with fiber optic links. The interconnection to the NASA Program Support Communications Network - Internet (PSCN-I) wide area network was also made with a fiber optic link to the government's long-distance telephone service provider under the Federal Trunking System (FTS). This service is known as FTS-2000.

The FTS-2000 service is provided in this geographical area by US West to the Las Cruces Central Office (LCCO) and then by American Telephone and Telegraph (AT&T) for interstate communications. FTS-2000 can support voice, video and data communication services on T-1 channels at 1.544 Mega-bits-per-second (Mbps) under their current government contract.

1.3 Scope

Over the period of WSC development, a number of dissimilar personal computing platforms, operating systems, and software applications had been acquired and used by the government and its contractors at the various WSC facilities. These have ranged from the early Commodore C-64™, Apple-II™, and International Business Machines (IBM) PC-XT™ types of computers up to the most recent Intel Pentium™, Sun SparcStation™, Apple Computer Power Macintosh™, and Digital Equipment Corporation (DEC) Alpha Stations™.

The scope of this project was to aggregate these dissimilar systems into one cohesive local area network (LAN) and wide area network (WAN) for information exchange and maintenance of information data bases.

To some extent, this was not possible; many of the older computers were not compatible with network computer operating systems. Intel™-based systems that were not at least based on the 86386 16-bit architecture microprocessor and Apple™ computers that were not based on at least the Motorola™ 68030 microprocessor have been classified obsolete and declared as excess equipment for disposition, except for a few that were kept for stand-alone applications.

Ethernet, conforming to the Institute of Electrical and Electronics Engineers (IEEE) specification 802.3, was selected for the LAN segments. The main segments were implemented using 10Base5 thick coaxial backbone copper cable runs. Some other segments were configured using 10Base2 thin wire coaxial copper cable runs. The majority of the office runs are 10BaseT configured with Category 5 unshielded twisted pair copper wiring.

The facility LAN segments are interconnected using fiber optics links, IEEE-802.3 10BaseF. For short runs (under 2000 meters) the links are configured using multimode (MM) fiber. For longer runs (over 2000 meters) the links are configured using singlemode (SM) fiber and Ethernet routers. Singlemode has lower optical attenuation and higher bandwidth per kilometer than multimode fiber.

The PSCN-I interface was provided by Marshall Space Flight Center (MSFC) under their charter for administrative wide area communication services. It consists of a T-1 (1.544 Mbps) partitioned gateway. One half of the bandwidth is allocated to a video teleconferencing service. One sixth of the bandwidth (256 Kbps) is allocated to the Internet WAN. One 56 Kbps circuit is allocated to teletype services and the remaining bandwidth is reserve.

The circuit originates at the NASA Johnson Space Center which is the regional NASA Internet hub. It is routed via AT&T fiber trunking services to Las Cruces and then brought to WSC by a US West tail circuit. The optical circuit is demultiplexed and converted to an electrical T-1 circuit at STGT where it is demultiplexed from the other T-1 traffic, rate buffered, and input to an Internet Email server before continuing to an Ethernet router configured as a security "firewall." The firewall provides local protection from unauthorized external intrusion into the WSC Administration LAN.

The PSCN-I gateway at STGT is also attached via a 56 Kbps copper link to another PSCN-I gateway at the White Sands Test Facility (WSTF) for backup in case there are problems with the primary link. This provides protection from singlepoint hardware failures at either of the PSCN-I gateways.

2.0 LITERATURE REVIEW

Selecting the network architecture required investigation of the alternatives that were available for constructing an administrative local area network. Several LAN hardware alternatives were available as well as several network operating systems and communication protocols. A decision was made that any LAN implementation would be based on standards established by various electrical and electronic engineering bodies such as: the Institute of Electrical and Electronics Engineers (IEEE), American National Standards Institute (ANSI), Electronic Industries Association (EIA), Telecommunications Industry Association (TIA), Military Standards (MIL-STD), and the International Standards Organization (ISO).

2.1 Open System Interconnect Review

The International Standards Organization (ISO) developed a layered network model called the Open Systems Interconnection Reference Model (OSI) [3] as a step toward international standardization for open computer communication protocols. This was an important first step away from proprietary systems and toward a universal set of communication layers that would permit and facilitate cross-platform data exchange. The OSI model has seven layers: 1) physical, 2) data link, 3) network, 4) transport, 5) session, 6) presentation, and 7) application which are arranged as shown in Figure 2-1. Where practical, the WSC Administration LAN was designed to this model. The major deviation is in the use of TCP/IP for the transmission and internetwork protocols. These standards predate the ISO Model and do not map directly onto it.

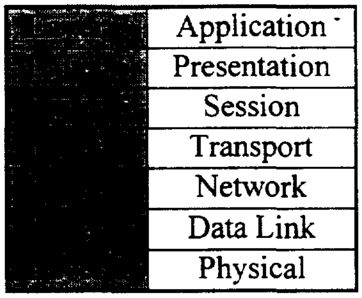


Figure 2-1
OSI Reference Model Layer Organization

The OSI layers provide the network services described in Table 2-1.

Table 2-1: The OSI Reference Model Layers [4]

Layer	Name	Definition
1.	Physical	Concerned with transmission of an unstructured bit stream over a physical link. Involves signal voltage swing and duration. Deals with mechanical, electrical, and procedural characteristics to establish, maintain, and deactivate the physical link.
2.	Data Link	Provides the reliable transfer of data across the physical link. Sends data blocks (frames) with synchronization, error control, and flow control.
3.	Network	Provides upper layers with independence from the data-transmission and switching technologies used to interconnect systems. Responsible for establishing, maintaining, and terminating connections across the network.
4.	Transport	Provides reliable, transparent transfer of data between end points, end-to-end error recovery, and flow control.
5.	Session	Provides the control structure for communication between applications. Establishes, manages, and terminates connections (sessions) between cooperating applications.
6.	Presentation	Performs transformations on data to provide a standardized application interface and common communications services. Examples include: encryption, text compression, and reformatting.
7.	Application	Provides services to the users of the OSI environment. Examples include transaction processing, file-transfer, and network management.

2.2 Physical LAN Architecture Review, ISO Layers 1 and 2

The two principal and established physical LAN architectures were Ethernet and Token Ring. Ethernet, pioneered by DEC, Intel and Xerox (DIX) [5], uses a random access methodology known as carrier-sense multiple access with collision detection (CSMA/CD) using baseband Manchester modulation over a coaxial cable. Token Ring, developed by IBM™, uses a deterministic system with an addressable token that is passed from computer to computer around an unshielded twisted-pair ring until the token address matches the receiving computer, then the token is acknowledged and the data transfer takes place. The cycle continues by the receiving computer placing a new token onto the ring. These two networks are designed to provide the physical and data link layers in the ISO Reference Model.

Both of these physical LAN architectures were *de facto* standards and in wide use before they were formally standardized by IEEE and later by ISO. Ethernet was designed to support a variety of computing platforms like DEC's VAX computers, Intel's x86-based computers, and various UNIX stations. Token Ring was popular primarily with IBM personal computer users, and Intel x86-based system.

The IEEE is accredited by the American National Standards Institute (ANSI) to develop American National Standards (ANS). The IEEE Computer Society formed a committee known as IEEE 802 to develop standards for LANs. These standards, labeled as ANSI/IEEE Std 802.x are submitted to ISO and a set of international standards, ISO 8802.x are then issued.

The IEEE 802 committee is organized into several subcommittees. Ethernet is in the purview of subcommittee 802.3 and Token Ring under 802.5. Common to all LANs is the requirement to manage access to a multiple-source, multiple-destination network. Subcommittee 802.2 is charged with development of standards for Logical Link Control (LLC). The current standards for LLC, Ethernet, and Token Ring are formalized in an IEEE publication first issued in 1985 [6] and updated in 1993 [7].

The IEEE 802.x organization follows the ISO model for the physical and data link layers. Several physical connections are provided. In addition to the two already discussed (Ethernet and Token Ring), provisions are made for a broadband coaxial Token Bus, Fiber Distributed Data Interface (FDDI), and optical fiber Token Ring operating at a clock rate of 100 Mbps. This organization is depicted in Table 2-2.

Table 2-2: IEEE Hierarchy and Relationship to LAN Standards [8]

Logical Link Control (LLC)	IEEE 802.2 • Unacknowledged connectionless service • Connection-mode service • Acknowledged connectionless service			
Medium-access control (MAC)	CSMA/CD	Token Passing Bus	Token Passing Ring	Slotted Token Ring
Physical	Baseband coaxial; 10Mbps Unshielded twisted pair; 1,10,100 Mbps Broadband coaxial; 10Mbps Optical fiber; 10,100 Mbps	Broadband coaxial; 1,5,10 Mbps Carrierband; 1,5,10 Mbps Optical fiber; 5,10,20 Mbps	Shielded twisted pair; 4,16 Mbps Unshielded twisted pair; 4 Mbps	Optical fiber; 100 Mbps
Designation	IEEE 802.3	IEEE 802.4	IEEE 802.5	IEEE 802.7

Ethernet was selected over Token Ring as the physical architecture because of technical merit, implementation ease and flexibility, and cost, and because of the software communication protocol most commonly used with this architecture, TCP/IP, was not proprietary. Token Ring operates primarily with a proprietary network operating system: Netware® from Novel™. FDDI was not considered because the implementation cost was much higher than the other implementations. The higher performance level was not needed for the WSC Administration LAN.

One project goal was to minimize dependence on vendor-specific proprietary solutions. Ethernet matches the OSI model for layers 1 and 2 with the physical media (cable plant) corresponding to the physical layer and the medium-access control with the logical link control together corresponding to the data link layer. This relationship is shown in Figure 2-2 [9].

Application		
Presentation		
Session		
Transport		
Network		
Data link	Maps to	Logical Link Control
		Medium-access control
Physical	Maps to	Physical
ISO Layer	Corresponds to	**IEEE 802.3 Ethernet**

Figure 2-2

Correspondence of IEEE 802.3 to the ISO Reference Model

2.3 LAN Communication Protocol Review, ISO Layers 3 and 4

Transmission Control Protocol and Internet Protocol were established Military Standards [10,11] and in wide government use for local and wide area networks before WSC began their LAN/WAN implementation. TCP/IP was also the communications protocol used on the Internet. This is logical since Internet grew out of the military's wide area network, ARPANET (Advanced Research Projects Agency Network) [12,13]. The Internet Protocol and Transmission Control Protocol, do not map exactly into the ISO Reference Model, but in general they correspond to the Network and Transport layers as shown in Figure 2-3.

Application		
Presentation		
Session		
Transport	Almost corresponds to	Transmission Control Protocol (TCP)
Network	Almost corresponds to	Internet Protocol (IP)
Data link	Maps to	Logical Link Control Medium-access control
Physical	Maps to	Physical
ISO Layer	Corresponds to	**IEEE 802.3 Ethernet**

Figure 2-3

Correspondence of TCP/IP to the ISO Reference Model

2.4 Network Operating System Selection Review, ISO Layers 5 and 6

Selection of the LAN Network Operating System was driven more by *de facto* standards than by national or international standards. Over the past decade, the original PC operating system, Disk Operating System (DOS) developed for IBM by Microsoft Corporation™ [14] and then later independently of IBM [15] became nearly the only choice of an operating system for Intel x86-based computers.

Most of the Reduced Instruction Set Computers (RISC) used a version of the UNIX operating system which was developed by Bell Laboratories™ in 1971 [16, 17]. Variants of UNIX that are based on the University of California at Berkeley's version 4.2 BSD (Berkeley Software Distribution), were equipped with a native LAN connection capability with a built-in software connectivity feature known as "sockets." UNIX 4.2 BSD was also designed to use TCP/IP protocols.

Many of the WSC computers are Apple Macintosh® variants. These computers use the Apple Operating System (OS) version 7.1 or 7.5 [18, 19]. Apple OS supports a type of networking called LocalTalk® which is a proprietary network solution. The newer Apple computers can also run a specialized version of Ethernet known as EtherTalk®. Because of non-conformance with established standards, connectivity of the Macintosh computers to the Administrative LAN required special hardware and software solutions to adapt the LocalTalk network to the TCP/IP network.

Microsoft evolved a more sophisticated user interface for DOS known as Windows® [20]. Windows version 3.1 could operate in a network using Microsoft's LAN Manager [21]. Windows integrated networking into the 1993 release of Windows for Workgroups® [22]. A more powerful version, Windows NT3.51® [23, 24, 25] is specifically designed for client and server networking. These operating systems support TCP/IP. Another popular new networking version of Windows, Windows95®, is not used at WSC.

The WSC LAN/WAN operates on a mix of the computers and computer operating systems discussed above. Servers include: Hewlett-Packard HP9000 operating with their version of UNIX known as HP-UX® [26]; Sun SparcStation 5 operating on SOLARIS® [27], Sun's UNIX variant; Gateway 2000 P5-90 and a Compaq ProSigna 500 operating with Windows NT3.51 server; a Compaq ProLinea 4/33 operating under Windows 3.1 with LAN Manager; a DECstation 5000/240 running DEC ULTRIX [28], DEC's own version of UNIX, and an Apple Macintosh Workgroup Server 8150 operating with OS 7.5.

Figure 2-4 shows the correspondence of the network operating systems and applications software with the ISO Reference Model.

Application	Corresponds to	Microsoft Office, in-house applications
Presentation	Corresponds to	Microsoft NT 3.51, HP-UX, ULTRIX, SOLARIS
Session	Corresponds to	Microsoft FTP/TELNET/LAN Mgr, NFS, Pathworks, Pacer
Transport	Almost corresponds to	Transmission Control Protocol (TCP)
Network	Almost corresponds to	Internet Protocol (IP)
Data link	Maps to	Logical Link Control Medium-access control
Physical	Maps to	Physical
ISO Layer	Corresponds to	**IEEE 802.3 Ethernet**

Figure 2-4

Network Operating Systems and Applications Compared to the Reference Model

The advantage of selecting TCP/IP for the network communications protocol becomes evident when such a diverse group of computers can interact, communicate and exchange information over a common channel.

2.5 Application Software Review, ISO Layer 7

Applications software becomes a matter of choice. Different people prefer and require different software applications. Because of the two "camps" of IBM PC-compatible and Apple Macintosh users, as much commonality as possible was desired in applications. One suite of applications that is available for both and can exchange applications between both is the Microsoft Office Suite® [29] which includes a word processor, a spreadsheet, a presentation graphics program, and a database. This report has been prepared using Microsoft Word® from that suite.

Many other applications are resident on the network. Some of them are network applications with the master copy or copies residing on a server. The client runs the application remotely. Others are dedicated to the user, although the user may make them available to others through a shared network directory.

The Macintosh Workgroup Server maintains engineering documentation such as on-line copies of engineering changes (ECs). The Gateway 2000 P5-90 server processes several applications: the logistics inventory management system (LIMS) for parts issue, another database called PROPERTY which keeps the physical property inventory records, and a database of local operating procedures (LOPs). The Compaq ProLinea 4/33 server processes and hosts the facilities database for

MAXIMO, a facilities maintenance tracking system. The HP9000 server processes the MAXIMO application and hosts the Engineering Operations (EOPS) drawings. The Sun SparcStation 5 is the Email server. A DECStation 5000/120 serves the Technical Library's Master List of current document revisions. A Compaq ProSigna 500 serves the Maintenance Tracking System (MTS) and is the primary WSC domain name server.

Description of the complete environment is not within the scope of this work and is not necessary for the reader's understanding of the network development.

3.0 MATERIALS AND METHODS

The IEEE 802.3 specification for Ethernet provides the physical and data link LAN layers. This specification provides several different implementations including: 1) 10BASE5, 2) 10BASE2, 3) 10BASE-T, and 4) 10BASE-F. The "10" refers to the media speed, 10 Mbps. The word "BASE" stands for "baseband," which is the type of signaling used. The third identifier indicates the approximate maximum segment length (or type). For thick coaxial segments, the "5" indicates that 500 meters is the maximum segment length. For thin coaxial segments, the "2" is a round-up of the 185 meter maximum total length. The "T" stands for "twisted-pair" and the "F" stands for "fiber optic." All of these implementations are used in the WSC Administration LAN. Each has certain advantages in application which are optimized for the implementation area.

Because of the selection of an open architecture primarily conforming to the OSI Reference Model for Open System Interconnect it was possible to host a wide variety of servers, desktop computers, operating systems, and applications on a common channel. This provides a much needed flexibility in implementation and potential to adapt to future changes and system growth.

Each of the main WSC facilities is equipped with an Administration LAN segment. The facilities are then interconnected with other Administration LAN segments. For short distances, the interconnection links are copper. For longer distances, fiber optic interconnections are used. The WSC facility layout and Administration LAN interconnection is shown in Figure 3-1.

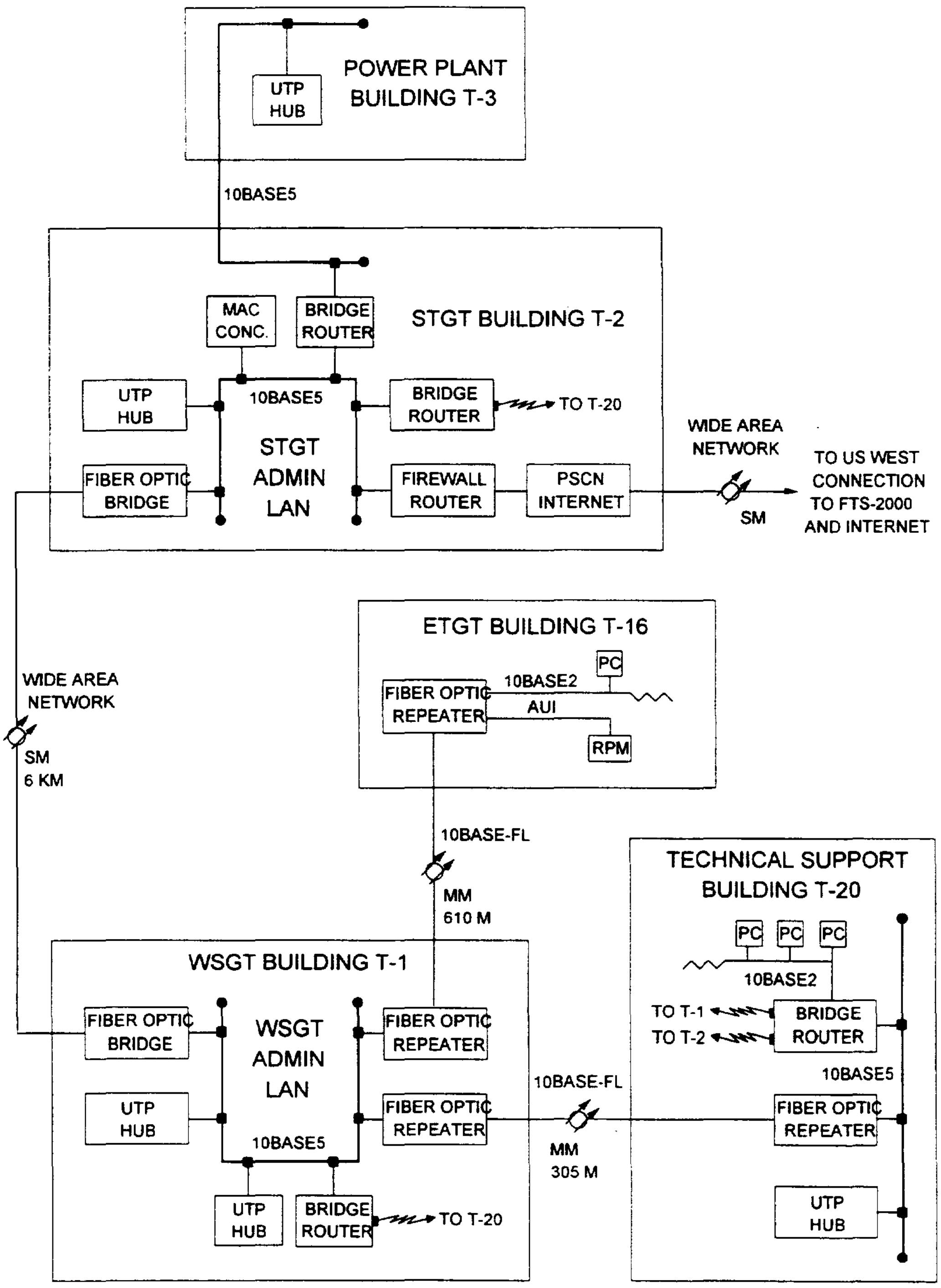


Figure 3-1

WSC Facility Layout and Administration LAN Interconnection

The primary backbone segment at each facility conforms to IEEE 802.3 10BASE5. This standard specifies a RG-8 type thick 50Ω coaxial cable of up to 500 meters in length. The backbone cable is routed throughout the facility providing attachment points for servers and distribution hubs. Medium-access units (MAUs or transceivers) can be attached to the 10Base5 cable at intervals of 2.5 meters.

Other segments may conform to the 10BASE2 specification which consists of RG-58A/U type thinwire 50Ω coaxial cable of up to 185 meters in overall length. Computers are attached in a daisy chain fashion in 10Base2 with the MAU or transceiver being integral with the network interface card (NIC) installed in the host computer's backplane.

Most WSC computers are attached to the LAN using 10BASE-T unshielded twisted pair wiring to distribution hubs. These runs can be as long as 100 meters. As in 10BASE2, the MAU is integral with the NIC. Most NICs have multiple ports so that they can attach to 10BASE5 with a 15-pin AUI cable, or a 50Ω BNC coaxial connector for 10BASE2, or a modular RJ-45 telephone jack for 10BASE-T.

Fiber optic links are used to interconnect facilities. If the separation distance is less than 2,000 meters, the facilities are connected via multimode fiber and 10BASE-FL Ethernet repeaters. These repeaters transmit and receive Ethernet packets using optical modulation at 850 nanometers (nm) wavelength over a multimode fiber that has a 62.5μ (micrometer) diameter core with 125μ diameter cladding.

Facilities over 2,000 meters apart are connected with fiber optic bridge/routers that transmit and receive Ethernet packets using optical modulation at 1310 nm wavelength over singlemode fiber that has a 8.3μ core with 125μ cladding. The connections for either type of fiber are made using ST® type connectors.

ST connectors were originally developed by AT&T. They use a bayonet-type "twist-lock" mounting arrangement and are available for both multimode and singlemode fibers.

3.1 Ethernet 10BASE5 Backbone Installations

Each main facility has an Ethernet backbone cable installation. This cable is a thick coaxial cable that is designed specifically for use in Ethernet systems. An example of a complying cable is Belden's 89880 which is fire code rated for plenum (air duct) service. This cable is approximately 1 cm in diameter, has a characteristic impedance of 50Ω, and has a solid center conductor. The maximum length of a 10BASE5 segment is 500 meters. Each end is terminated into a male type "N" coaxial connector. A 50Ω female type "N" terminator is attached at each end. One end is grounded. This is the only ground permitted in the cable system. Medium attachment units can be installed on the backbone cable at 2.5 meter intervals. These intervals are marked on the cable with a black stripe during manufacturing. Up to 100 MAUs can be attached to any one 10BASE5 segment. The MAU was called a *transceiver* in the original DIX Ethernet standard [5] because it both ***trans***mits and re***ceive***s signals on the transmission medium, in this case, the 50Ω coaxial cable.

The MAU is an external unit that provides an electrical interface to the thick coaxial 10BASE5 cable and transfers signals between the Data Terminal Equipment (DTE) and the Ethernet segment. The transceiver is powered from the DTE via the transceiver cable. The MAU also provides a signal known as the Signal Quality Error (SQE) Test Signal which is transmitted between the transceiver and the DTE during the interframe gap to test the collision detection electronics of the MAU. This signal is also known as the "heartbeat signal." It may be disabled if desired. It is never transmitted over the network and does not delay frame transmissions. The SQE signal must be disabled when a MAU is connected to a repeater otherwise the repeater will interpret the SQE test as a collision after every frame it transmits. It will then send out a jam signal to make sure each DTE on the repeater knows about the "collision." This causes inefficient network utilization because the SQE test signal is not really a collision.

The MAU is attached to the medium (cable) with a medium dependent interface (MDI). For the thick coaxial medium, the MAU is usually attached to the cable with a plastic and metal clamp designed by the AMP corporation and known as the "AMP tap." The clamp requires that a hole be drilled into the cable to access the center conductor while brads penetrate the cable's outer jacket to make electrical contact with the shielding braid. This kind of tap can be installed while the network is active so it is called a "non-intrusive" tap. An "intrusive tap" requires cutting the cable at one of the marked intervals and installing type "N" connectors for the tap which has mating type "N" connectors on its body. Intrusive taps are good for joining different thick coaxial cable segments together and non-intrusive taps are preferred for attaching DTE to the network.

The MAU is connected to the DTE via an AUI cable which is the attachment unit interface, called a transceiver cable in the DIX specification. The AUI cable can be up to 50 meters long. The AUI cable mates to a 15-pin subminiature-D male connector on the MAU and mates to a 15-pin subminiature-D female connector on the NIC which is installed in the DTE. The NIC is also known as the Ethernet or network interface card.

An illustration of the components of a typical backbone 10BASE5 system is shown in Figure 3-2 below:

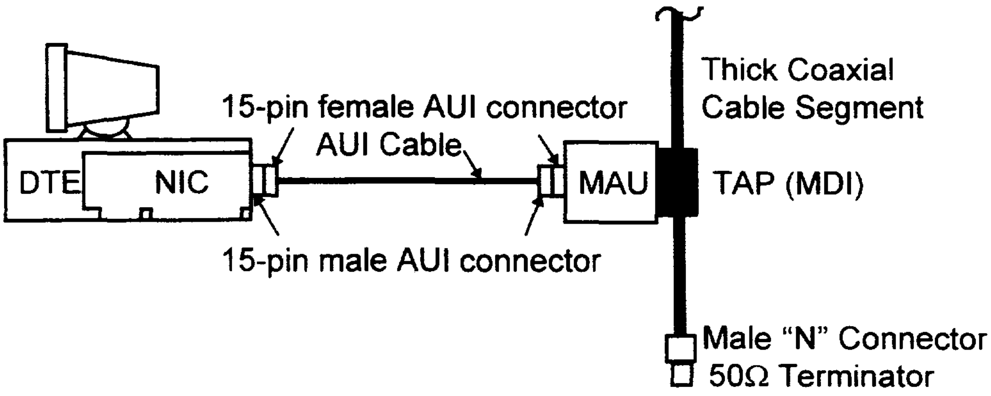


Figure 3-2

Components of a 10BASE5 Ethernet System

Ethernet 10BASE2 Thinwire Installations

Thinwire Ethernet was used in the Logistics area in the Technical Support Building (TSB), T-20, and in the Extended TDRS Ground Terminal (ETGT), T-16 because of simplicity when only a few computers need to be attached to the network.

The thin coaxial cable used in 10BASE2 is much more flexible and can be connected directly to the network interface card in the computer. Most NICs have provisions for all three major types of connectivity: 1) AUI 15-pin connector for 10BASE5, 2) BNC for 10BASE2, and 3) RJ-45 for 10BASE-T. When a NIC is connected to a thinwire segment via the female BNC connector, the AUI, MAU, and MDI are all part of the NIC in the computer. This simplifies the number of components needed and reduces the cost to connect a computer to the network.

An illustration of the components of a typical thinwire 10BASE2 system is shown in Figure 3-3 below:

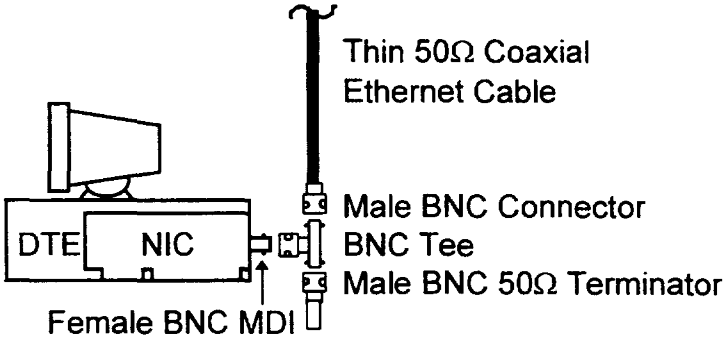


Figure 3-3

Components of a 10BASE2 Ethernet System

The network medium is RG-58A/U, a 50Ω coaxial cable approximately ½ cm in diameter. The cable is equipped with male BNC connectors at each end. The segment is configured in a "daisy chain" fashion. Up to 30 MAU connections are allowed on each thinwire segment of 185 meters (rounded up to "2" in the shorthand identifier 10BASE2). There is no special spacing rule; however, no one section can be shorter than ½ meter. Figure 3.4 shows how this would work for three DTE connections. The entire segment cannot be longer than 185 meters and the shortest cable section in the segment cannot be shorter than ½ meters. Stub cables from the NIC to the BNC Tee are not allowed.

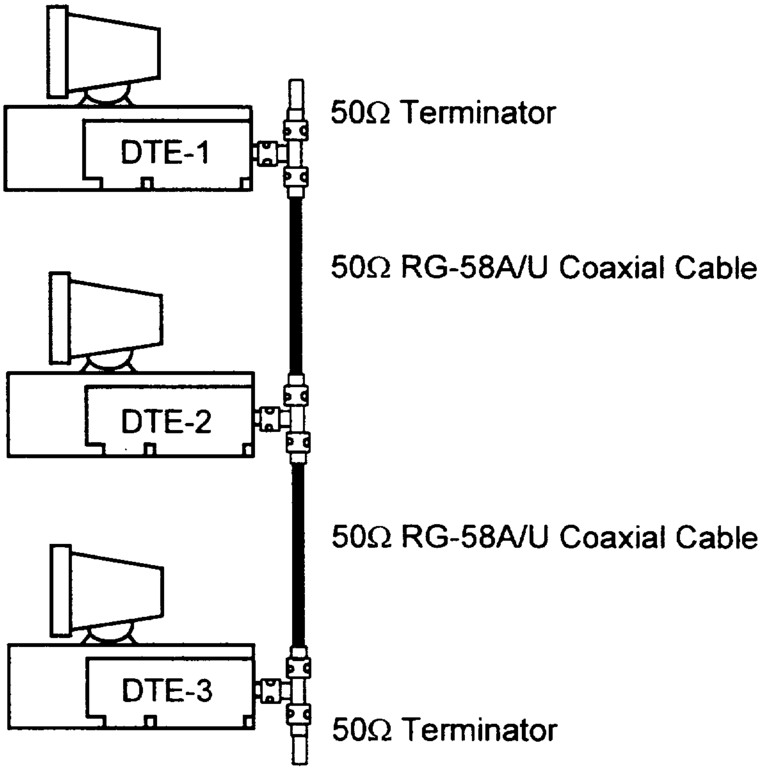


Figure 3-4

A Three-DTE Configuration for a 10BASE2 Ethernet System

3.3 Ethernet 10BASE-T Unshielded Twisted-Pair Installations

The specification for 10BASE-T refers to unshielded twisted-pair (UTP) wiring used for this type of Ethernet. Two pairs of wire are used. One pair is used for transmitting data signals and the other pair for receiving data signals. Each twisted-pair segment can be up to 100 meters in length when used with a Category 3, 4 or 5 cable [30, 31] as specified by the Electronics Industries Association and Telecommunications Industries Association (EIA/TIA). All three categories specify four unshielded twisted-pairs of 24 average wire gauge (AWG) thermoplastic insulated conductors enclosed in a thermoplastic jacket. These cables have a characteristic impedance of 100Ω.

The characteristics of Category 3 cable are specified up to 16 MHz. This cable is typically used for voice and data transmission rates up to 10 Mbps (i.e. IEEE 802.3 10BASE-T). Category 4 cable is specified up to 20 MHz and is intended to be used for voice and data transmissions up to and including 16 Mbps (i.e. IEEE 802.4 Token Ring). Category 5 cable is specified up to 100 MHz and is intended for use with an emerging standard for 100 Mbps Ethernet, 100BASE-T [32]. Category 3 cable has a mutual capacitance of 20 nF per 305 meters. Categories 4 and 5 have a lower capacitance value of 17 nF per 305 meters. Attenuation in these cables increases with increasing frequency. The higher number categories have lower attenuation because they are designed for higher frequencies and data rates. The WSC installations have used both Category 3 and Category 5 cabling. Where available, extra Category 3 telephone cable that was already installed to an office was used. When new 10BASE-T drops were installed, Category 5 wire was used.

The MDI for 10BASE-T is an eight-pin RJ-45 telephone jack. The system uses two pairs of wires, so four pins of the eight-pin jack are used and four pins are unused. Two standard jack wiring conventions are used as shown in Figure 3-5 below [33]. This wiring is used on the jack to connect to the NIC card in the computer and is also used on the wall plate jack in the office and at the hub. Each 10BASE-T segment has a maximum two MDIs and MAUs.

The Administrative LAN uses wiring per designation T568A and the Software Maintenance and Training Facility (SMTF) LAN uses designation T568B. The two LANs have different security classification levels so different wiring prevents data communications if a computer is inadvertently connected to the wrong LAN. The connector nomenclature is for transmit and receive pairs and wire color code.

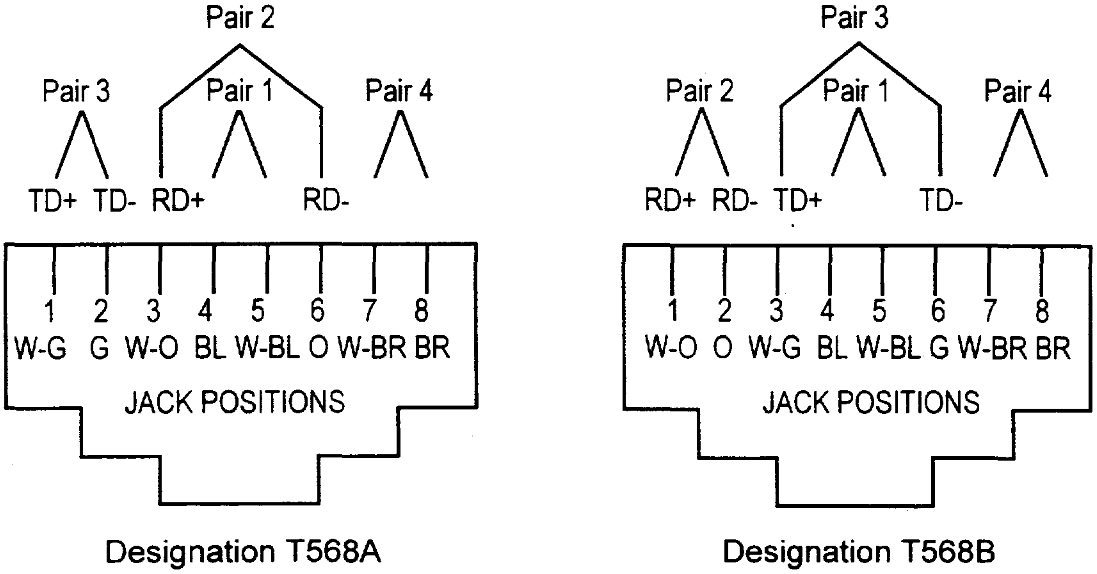


Figure 3-5

MDI Wiring for 10BASE-T [33]

Computers are usually attached to hubs in the 10BASE-T configuration. A hub, internally, is an Ethernet repeater or a collapsed backbone. A hub is sometimes called an Ethernet-in-a-box. Hubs come with different numbers of ports. A small hub would have four ports and a large hub would have 24 ports and be expandable to attach to other hubs. The hub is usually connected to a thick backbone segment; however, they can be daisy chain connected with hub expansion cables. Most of the computers attached to the Administration LAN at WSC are connected to hubs which are connected to thick backbones. A typical hub arrangement is shown in Figure 3.6.

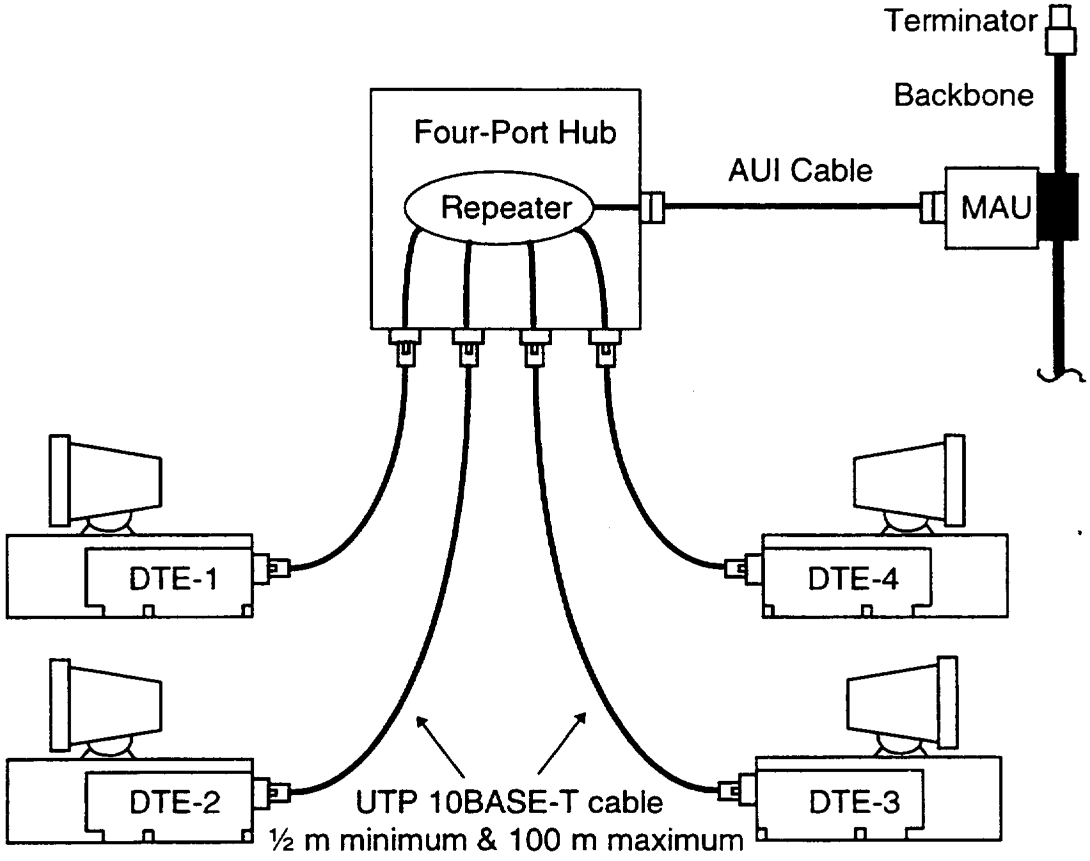


Figure 3-6

A Typical 10BASE-T System Configuration

3.4 Ethernet 10BASE-F Fiber Optic Installations

The 10BASE-F fiber optic media system transmits data signals with pulses of light instead of by electrical currents. This specification has been recently updated

[34] to provide three types of fiber optic connectivity. The most common type and the only one employed at WSC is 10BASE-FL where FL indicates fiber link. The 10BASE-FL standard replaces an older fiber optic inter-repeater link (FOIRL) specification. The 10BASE-FL standard provides for a point-to-point link segment connecting two MDIs over a distance of up to 2,000 meters. FOIRL provided the same capability for a link of up to 1,000 meters. The other parts are 10BASE-FB where FB indicates fiber backbone and 10BASE-FP where FP indicates fiber passive.

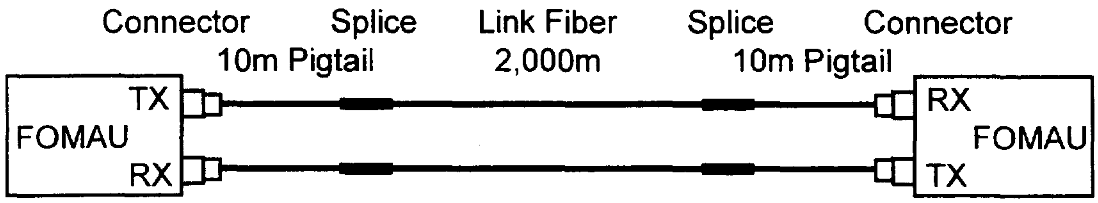
The 10BASE-FB specification provides for a synchronous signaling backbone that allows more than two repeaters. Each repeater link can be up to 2,000 meters in length. This type of link was not used at WSC on the 6,000 meter link between WSGT and STGT because there are no intermediate access points to the fiber cable.

The 10BASE-FP specification provides a fiber passive system that provides an optical mixing segment that links multiple computers without using repeaters. This system has not been widely adopted and equipment is generally unavailable.

The optical fiber used for 10BASE-FL is a multimode optical waveguide, so called because it has a core diameter that is large when compared to the optical wavelength of the signal and in which consequently, a large number of modes are capable of propagation. Modes are eigenvalue solutions to the differential equations which characterize the waveguide and are discrete optical waves that can propagate in

The typical multimode fiber used in 10BASE-FL has a core diameter of 62.5 microns and a cladding diameter of 125 microns. This is usually expressed in shorthand as 62.5μ/125μ fiber. The index of refraction of the core is less than the index of refraction of the cladding and this causes the wave to be guided back into the core when it encounters the core/cladding interface. This is an effect of Snell's Law. an optical waveguide.

The connectors are specified to be AT&T's ST®. This is a bayonet-type connector that holds the two fibers in optical alignment. The wavelength of light used is 850 nm and the budget for a link segment must be no greater than 12.5 dB of optical loss. The optical loss is a result of attenuation through the fiber, splicing losses, and connector coupling losses. A typical multimode fiber will have an attenuation of about 4 dB/km at this wavelength. Splice and connector coupling losses are usually approximated as ½ dB each. So, a typical link could be characterized as shown below in Figure 3-7:



Losses: 0.5dB + 0.04dB + 0.5dB + 8dB + 0.5dB + 0.04dB + 0.5dB

Total Link Budget = 10.08 dB
Margin = 1.92 dB

Figure 3-7

Typical 10BASE-FL Fiber Optic Link System and Budget

At WSGT, 10BASE-FL links were used to connect the Technical Support Building T-20 and ETGT Building T-16 to the WSGT main facility, Building T-1.

Figure 3.8 below shows how these three facilities at WSGT have been interconnected using 10BASE-FL links.

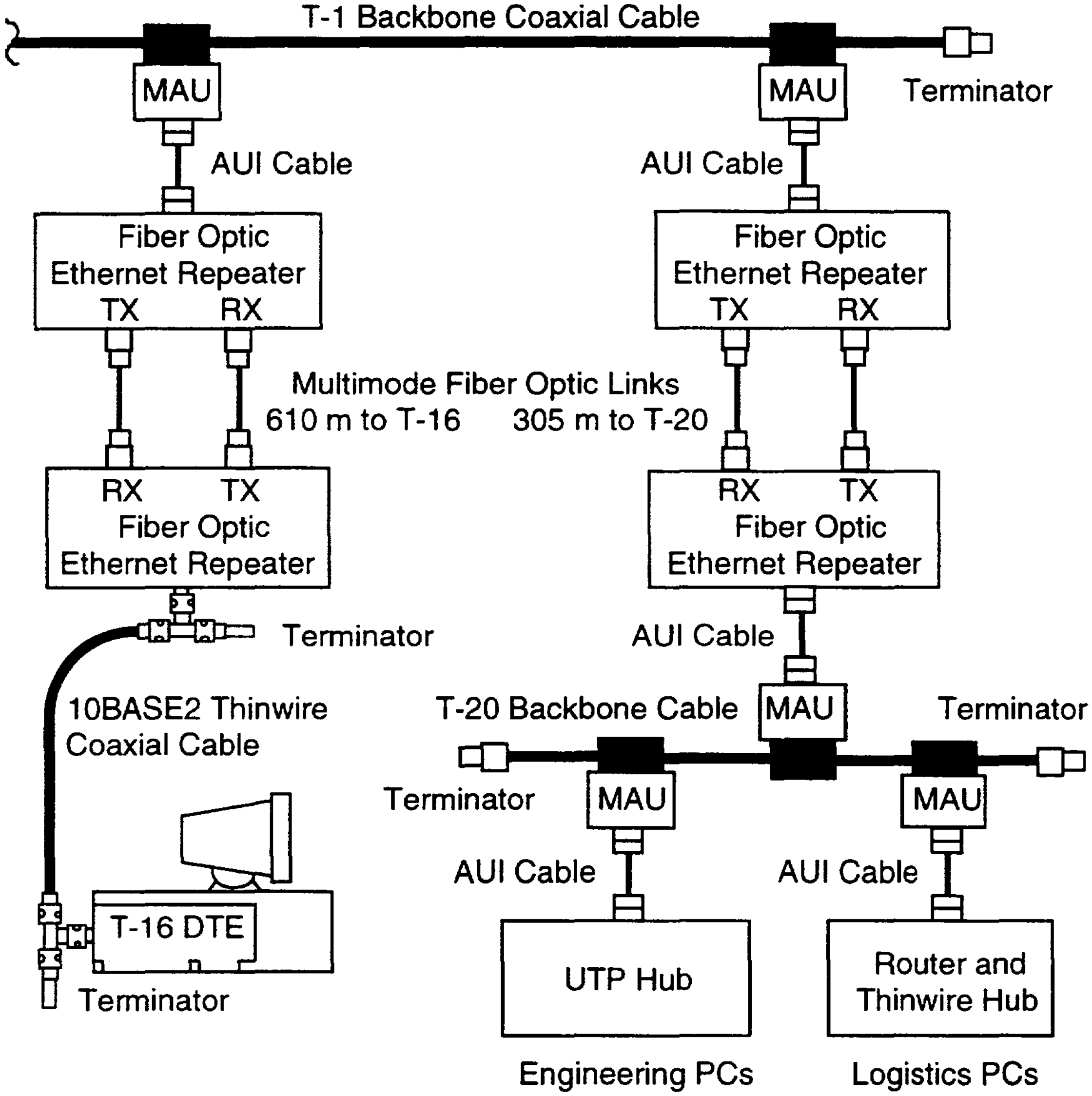


Figure 3-8

Fiber Optic Connectivity from the T-1 Building to the T-16 and T-20 Buildings

WSGT and STGT, are too far apart to connect together using 10BASE-FL. The distance between facilities is about three miles and they are interconnected by a singlemode fiber optic installation known as the NASA Communications Inter-Facility Link (NASCOM IFL) which is about 6,000 meters in length. This is three times the maximum length for 10BASE-FL and the fiber is not multimode.

The main buildings, T-1 at WSGT and building T-2 at STGT, have been connected in a wide area network (WAN) using singlemode fiber optic bridges as shown in Figure 3.9. Fiber links have distinct advantages, especially for interconnecting different buildings at a facility. Fiber is electrically non-conductive, so there is never a problem with different grounding potentials at different buildings. The fiber is immune to electromagnetic interference and does not emit electromagnetic radiation which means that it protects the signals from transient spikes due to lightning while providing inherent data security. Fiber also has higher bandwidth capability than copper and can operate at the 10 Mbps Ethernet data rate and can also support the newer 100 Mbps data rate. Both of the coaxial copper Ethernet standards, 10BASE2 and 10BASE5 are restricted to the 10 Mbps rate. Fiber implementation cost has decreased to the point where it is economically competitive with copper links.

Increased complexity in installation is one of the primary drawbacks to fiber because special tooling, training, and test equipment are required. The optical sources represent a health hazard. The transmitted light is not visible but can burn the retina. This is more likely with a laser source than with a light emitting diode (LED) source.

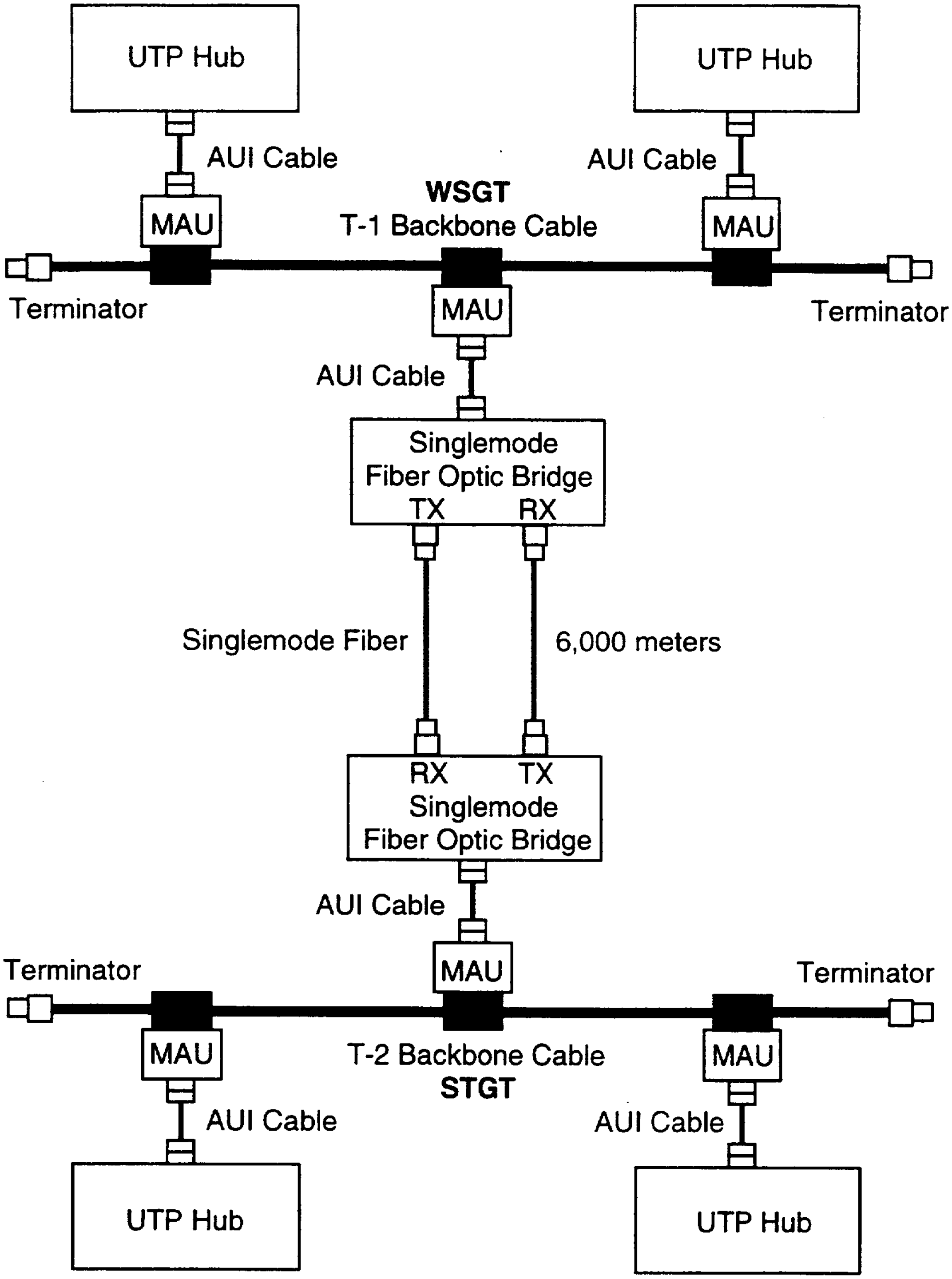


Figure 3-9

Wide Area Network Connection of WSGT to STGT

3.5 Multi-Segment Configuration Guidelines, General Case

The IEEE 802.3 standard provides two models for verifying the configuration of multi-segment baseband Ethernets. Transmission System Model 1 provides a set of general guidelines for individual "collision domains." Segments that are joined by hubs and repeaters form one collision domain.

Ethernet routers, bridges, and switches create separate collision domains. In the WSC configuration a bridge is used to connect WSGT to STGT; therefore, WSGT is one collision domain and STGT is another.

3.5.1 General Case Configuration Guideline Rules

The general case rules provided by the IEEE Model 1 provide a quick way to assess the validity of any given multi-segment Ethernet configuration. The proper operation of a CSMA/CD network requires the network size to be limited to meet the IEEE allowable parameters [35] given in Table 3-1 below:

Table 3-1: Allowable Parameters for a 10 Mbps CSMA/CD Implementation [35]

Parameters	Values
slotTime	512 bit times
interFrameGap	9.6 μs
attemptLimit	16
backoffLimit	10
jamSize	32 bits
maxFrameSize	1518 octets
minFrameSize	512 bits (64 octets)
addressSize	48 bits

The following network topology constraints apply to multi-segment Ethernet configurations, as taken from the IEEE standard [36]:

1) Repeater sets are required for all segment interconnections

2) The MAUs that are part of repeater sets count toward the maximum number of MAUs on a segment

3) The transmission path permitted between any two DTEs may consist of up to five segments, four repeater sets (including optional AUIs), two MAUs, and two AUIs.

4) AUI cables for 10BASE-FP and 10BASE-FL shall not exceed 25 m. (Since two MAUs per segment are required, 25 m per MAU results in a total AUI cable length of 50 m per segment).

5) When a network patch consists of four repeater sets and five segments, up to three of the segments may be coaxial and the remainder must be link segments. When five segments are present, each fiber optic link segment (FOIRL, 10BASE-FB, or 10BASE-FL) shall not exceed 500 m, and each 10BASE-FL segment shall not exceed 300 m.

6) When a network path consists of three repeater sets and four segments, the following restrictions apply:

    - The maximum allowable length of any inter-repeater fiber segment shall not exceed 1000 m for FOIRL, 10BASE-FB, and 10BASE-FL segments and shall not exceed 700 m for 10BASE-FP segments.
    - The maximum allowable length of any repeater to DTE fiber segment shall not exceed 400m for 10BASE-FL segments and shall not exceed 300 m for 10BASE-FP segments and 400 m for segments terminated in a 10BASE-FL.
    - There is no restriction on the number of mixing segments in this case.

3.5.2 WSC System Configuration Comparison

The White Sands Complex has five collision domains. There are three configurations to examine against the general configuration rules: at WSGT, including the fiber optic extension to T-20; the LAN extension to ETGT; and at STGT. The T-3 Power Plant and T-20 Logistics LANs are very simple.

WSGT has eight segments: two 10BASE5 mixing segments, five 10BASE-T segments, and one 10BASE-FL segment. STGT has five segments: one 10BASE5 mixing segment and four 10BASE-T segments. Figure 3.10 shows the details of the WSGT installation and Figure 3.11 shows the details of the STGT configuration. The Power Plant Building has two segments: one 10BASE5 and one 10BASE-T as shown in Figure 3-12. The Technical Support Building T-20 Logistics area has one 10BASE2 segment; the rest of T-20 is part of the WSGT configuration. This is shown in Figure 3-13. ETGT has four segments. One each of 10BASE5, 10BASE2, 10BASE-T, and 10BASE-FL. Figure 3-14 shows this configuration.

At WSGT, the 10BASE5 segment in Building T-1 is 300 meters long. The 10BASE5 segment in Building T-20 is 20 meters long. The 10BASE-FL segment from T-1 to T-20 is 305 meters long. The longest unshielded twisted pair link in the 10BASE2 segment is 100 meters in length from a T-20 hub to the Guard Shack. The longest 10BASE2 segment in T-1 is 90 meters long. All AUI cables are 10 meters or less in length. The worst-case between DTEs falls under rule 6). There are four segments, three repeaters, and a 10BASE-FL segment of 305 meters for one DTE in T-20 communicating with another in T-1. The configuration guideline rules are met.

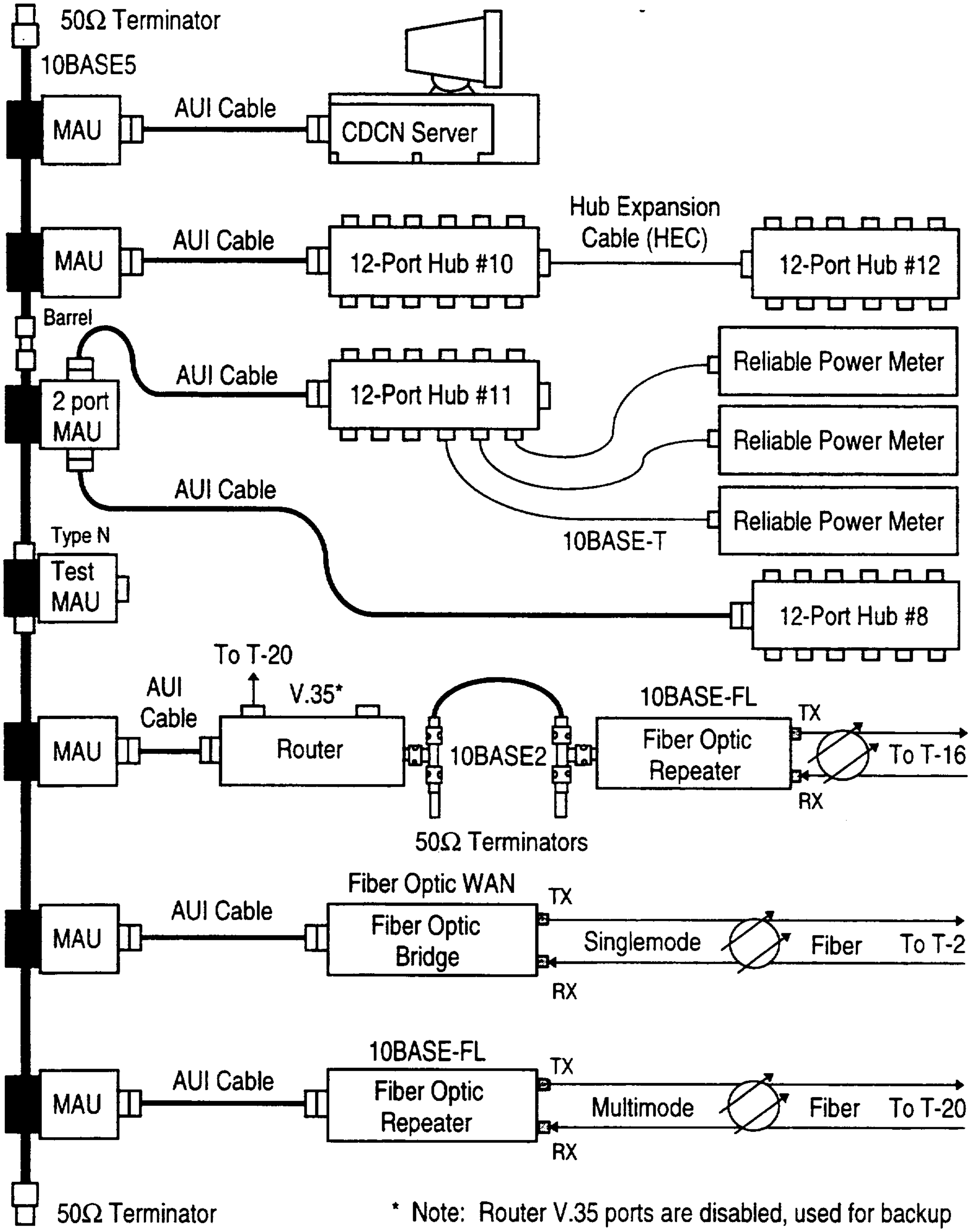


Figure 3-10

Installation Details of the WSGT Building T-1 Administration LAN

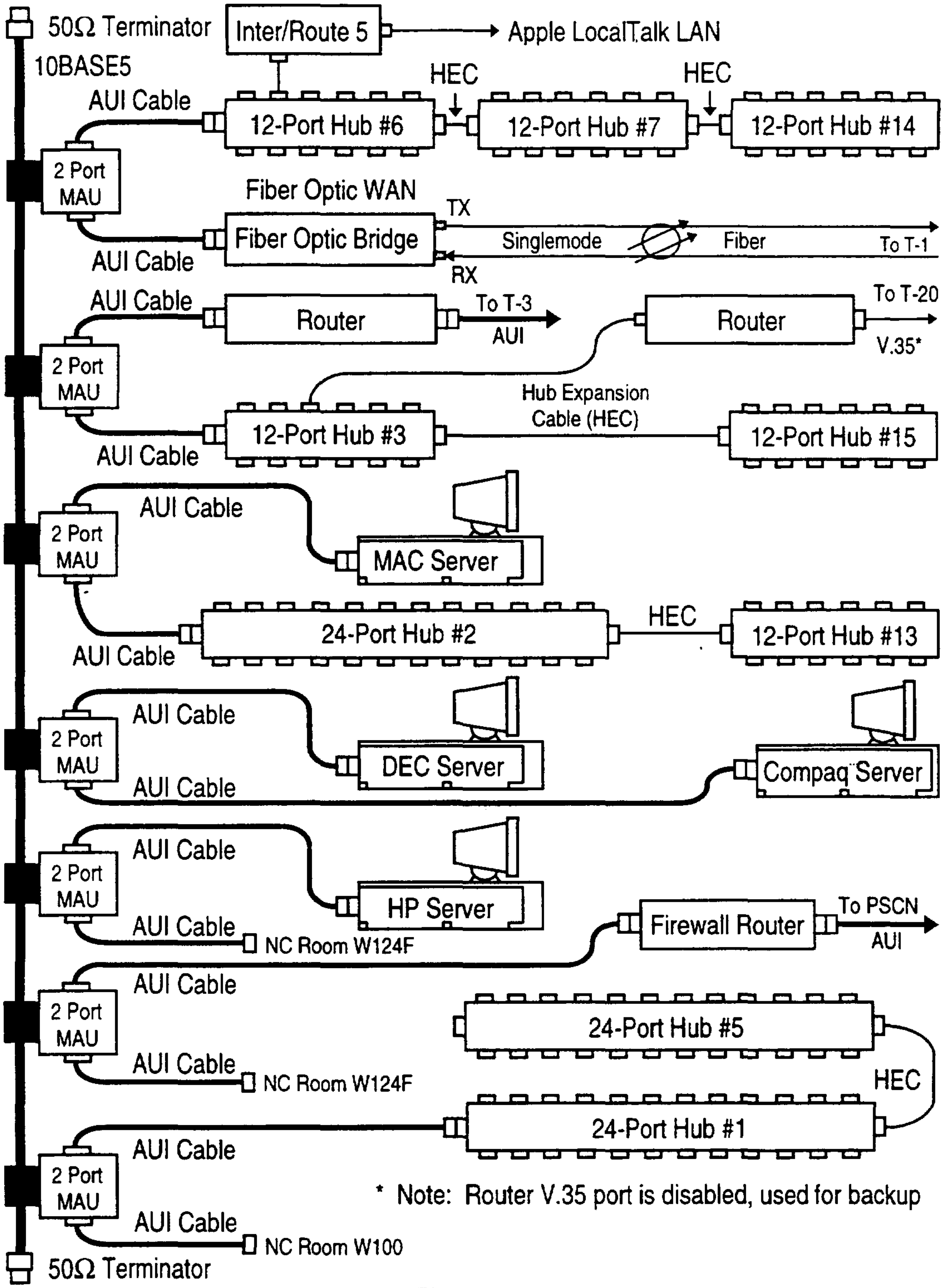


Figure 3-11

Configuration Details of the STGT Building T-2 Administration LAN

The STGT LAN has one 260 meter long 10BASE5 mixing segment in the T-2 building. The longest 10BASE-T cable run exceeds the recommended maximum of 100 meters. The AUI cables are all 10 meters or less in length. The most distant DTEs would have three segments with two repeaters between them. This installation does not appear to meet the general guideline rules, a detailed analysis is required.

The T-3 Power Plant LAN has two segments: one 10BASE5 and one 10BASE-T. The 10BASE5 segment is 110 meters long and the longest 10BASE-T run is approximately 20 meters. This simple installation meets the guidelines.

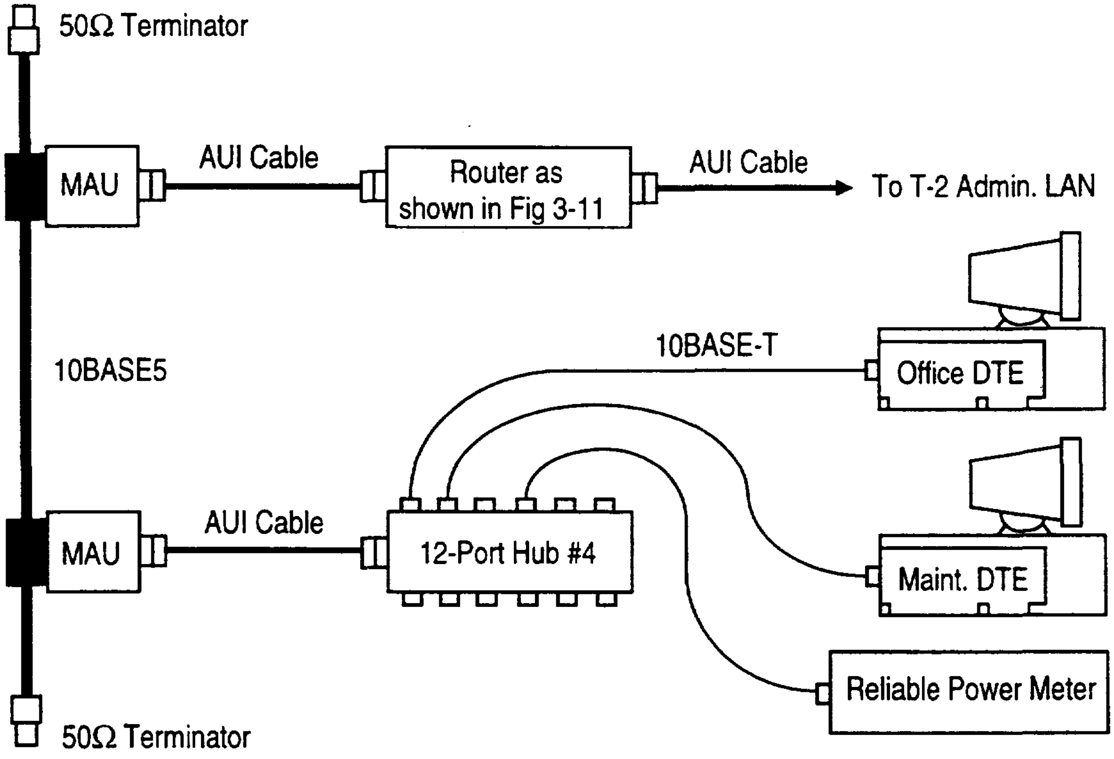
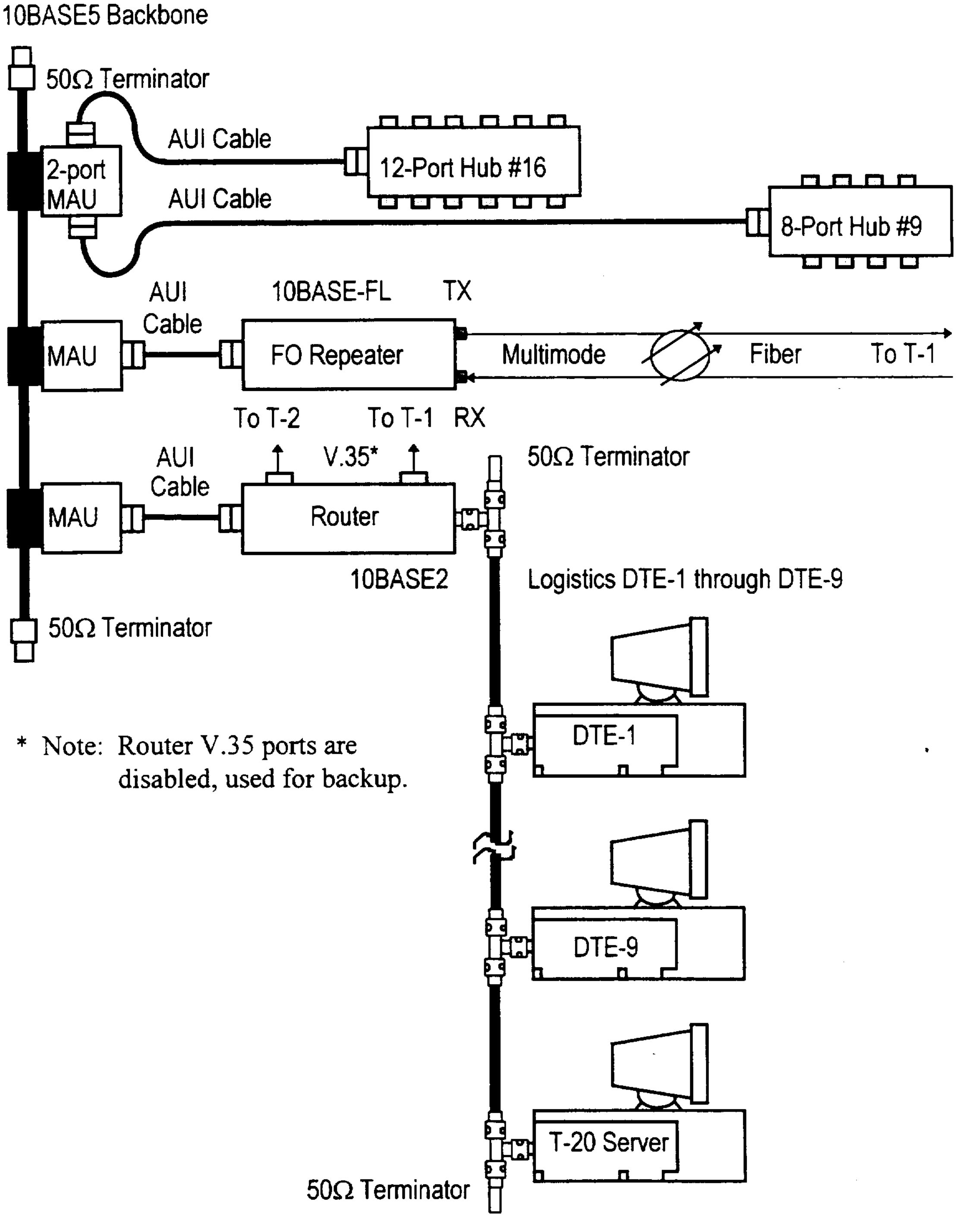


Figure 3-12

Configuration Details of the STGT Power Plant Building T-3 Administrative LAN



* Note: Router V.35 ports are disabled, used for backup.

Figure 3-13

Configuration Details of the Technical Support Building T-20 Administration LAN

The T-20 Logistics 10BASE2 segment shown in the previous figure is a single segment after the router. This segment is 170 meters long which is under the maximum length of 185 meters, so it meets the general configuration guidelines. The rest of the T-20 Administration LAN configuration is part of the WSGT T-1 configuration because it is connected via a 10BASE-FL repeater and not by a router.

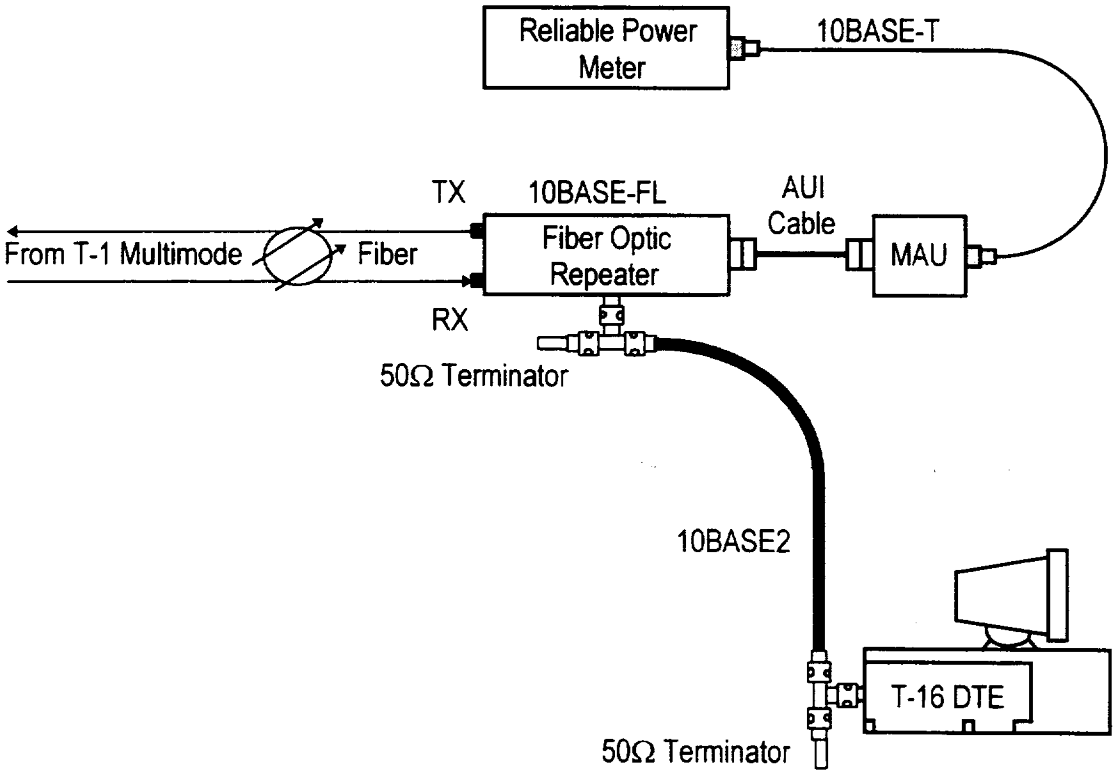


Figure 3-14

Configuration Details for ETGT Building T-16 Administration LAN

Building T-16 has a 10BASE5 and a 10BASE2 segment connected to a 10BASE-FL segment to Building T-1 where it is connected to a router via a 10BASE2 segment. Configuration guidelines rule 6) is the most applicable one. The most distant DTEs would connect via one repeater and a 610 meter 10BASE-FL link. This installation also meets the general configuration guidelines.

3.6 Multi-Segment Configuration Guidelines, Complex Installations

The second IEEE configuration model provides a set of calculations which makes it possible to test the validity of more complex Ethernet systems. There are two parameters to be calculated for each collision domain: the worst-case round-trip signal delay time and the interframe gap shrinkage. The model is based on defining the worst-case path from one DTE in the collision domain to another. Worst-case implies the maximum separation distance and the most segments and repeaters in the path. The information for the second configuration model is simplified and more accessible in a book by Spurgeon [36] where clear examples are provided. A network model for round-trip timing is given in Figure 3-15 below:

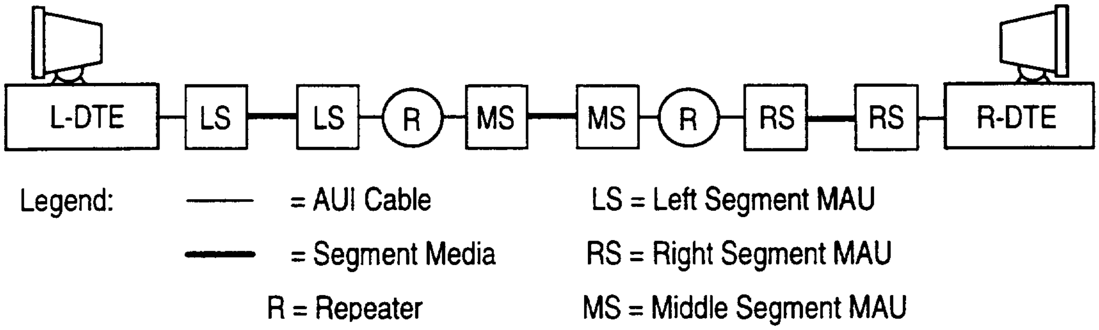


Figure 3-15

Network Model for Round-Trip Timing

The model includes a left-end segment, a right-end segment, and as many middle-segments as needed to describe the worst-case path in the collision domain.

3.6.1 Calculating the Round-Trip Delay Time

Any two DTEs are supposed to be able to fairly contend for access to the shared Ethernet channel at the same time. When this happens, each transmitting station is notified of channel contention, a collision, by receiving a collision signal within a specified collision timing window. The dynamics of collision handling are largely determined by a parameter called the slotTime given in Table 3-1 as 512 bit times. This is combined with the jamSize parameter to set an upper bound on round-trip transmission delay through the network.

The slotTime sets an upper bound on the acquisition time of the Ethernet channel. It is an upper bound on the length of a frame fragment generated by a collision. And, it is the scheduling quantum period for retransmission of a frame impacted by a collision. When a collision is detected during a transmission, the transmission is not halted immediately but continues until 32 more bits are transmitted. These additional bits are known as the jamSize and are used for collision enforcement by guaranteeing that the duration of the collision is sufficient to ensure detection by all of the DTEs on the network.

DTEs at the worst-case ends of the network have to be able to detect collisions within these times to assure proper operation of the network. The configuration rule is to ensure that a DTE at the end of a worst-case path will not send more than 511 bits of a frame plus the 64 bits of the frame preamble and start frame delimiter, or 575 bit times. For this to be assured (with a five bit margin), the total round-trip delay for the worst-case path in the system must be less than 570 bit times.

To find the total round-trip path delay of the worst-case path the delay time must be determined for each segment in the path. This is done in terms of bit propagation time in the various IEEE 802.3 media. Table 3-2 gives the IEEE bit time delay values for the media types. The length of the segment is multiplied by the delay per meter factor for the media type and that value is added to the "base" media value. This is done for each left-end, middle, and right-end segment and the results are totaled. Next the left-end and right-end segments are swapped and the calculations are repeated. The worst-case path must be less than 570 bit times in each direction.

Table 3-2: IEEE 802.3 Round-Trip Delay Bit Times [37]

Segment Type	Maximum Length meters	Left-End Segment		Mid-Segment		Right-End Segment		Round-Trip Delay/meter
		Base	**Max**	**Base**	**Max**	**Base**	**Max**	
10BASE5	500	11.75	55.05	46.5	89.8	169.5	212.8	0.0866
10BASE2	185	11.75	30.731	46.5	65.48	169.5	188.48	0.1026
10BASE-T	100	15.25	26.55	42	53.3	165	176.3	0.133
10BASE-FL	2,000	12.25	212.25	33.5	233.5	156.5	356.5	0.1
Excess AUI	48	0	4.88	0	4.88	0	4.88	0.1026

3.6.2 Calculating the Interframe Gap Shrinkage

A delay of 96 bit times is provided between frame transmissions to allow the network time to recover. This delay is called the interframe gap. As frames propagate through the LAN variable timing delays in the network components and frame reconstruction in repeaters can result in shrinkage of the interframe gap. If the gap becomes too small, frames can become lost because they start to overlap. Therefore, it is important to maintain a minimum interframe gap.

The interframe gap shrinkage is checked using the same basic network model as for checking the round-trip path delay, except that it includes transmitting and receiving end segments. This model is shown in Figure 3-16 below:

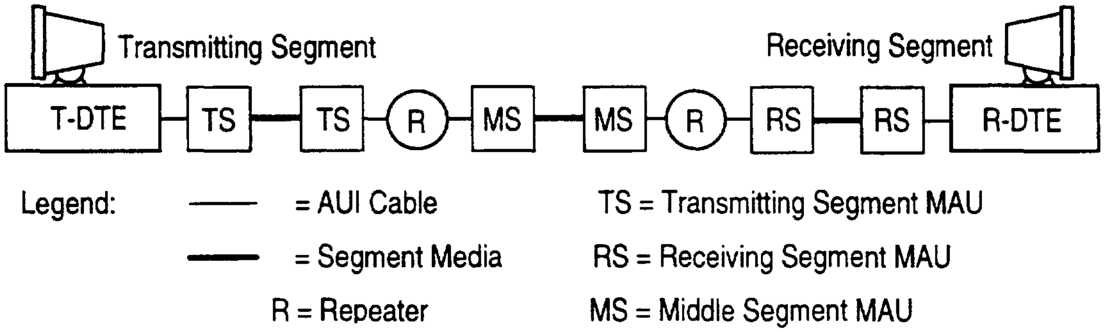


Figure 3-16

Network Model for Interframe Gap Shrinkage

The calculations for interframe gap shrinkage only consider the transmitting and middle segments. The receiving segment does not contribute to the interframe gap shrinkage. The end segment with the largest interframe gap shrinkage is used for the transmitting end to provide a worst-case value. If the total shrinkage is less or equal to 49 bit times, the network passes this test. Table 3-3 provides the data required to compute the interframe gap shrinkage.

Table 3-3: Interframe Gap Shrinkage in Bit Times [38]

Segment Type	**Transmitting End**	**Mid-Segment**
10BASE5 or 10BASE2	16	11
10BASE-T or 10BASE-FL	10.5	8

3.6.3. Finding the Worst-Case Path

The worst-case in the network is the one with the most delay. It will have the longest round-trip propagation time and the largest number of repeaters between two different DTEs. With complicated networks, there may be several combinations that look to be worst-case. If that is so, then it is necessary to perform the calculations for each to find the mathematical worst-case. It is not always possible to select the actual worst-case path by inspection.

After a candidate for the worst-case path is identified, a model of the path is made and the calculations are performed with each end-segment first being the left-end segment and then the right-end segment. All other segments in the path are middle segments.

3.6.4 Comparison of WSC Configuration to Guidelines

The WSC configuration has several possibilities for worst-case path. Each must be examined in turn to determine the overall operability of the network. At WSGT the worst-case path would be from the Building T-21 Guard Shack computer through the 100 meter UTP end-segment to a 10BASE-T hub which is connected to the short T-20 10BASE5 mid-segment. The 10BASE5 mid-segment connects to T-1 via a 305 meter 10BASE-FL mid-segment. The other end of the 10BASE-FL mid-segment connects to the T-1 10BASE5 mid-segment and it connects to another 10BASE-T hub with a 90 meter UTP end-segment to another computer in T-1. The next step is to create a model of this configuration for analysis. Figure 3-17 shows the WSGT worst-case configuration.

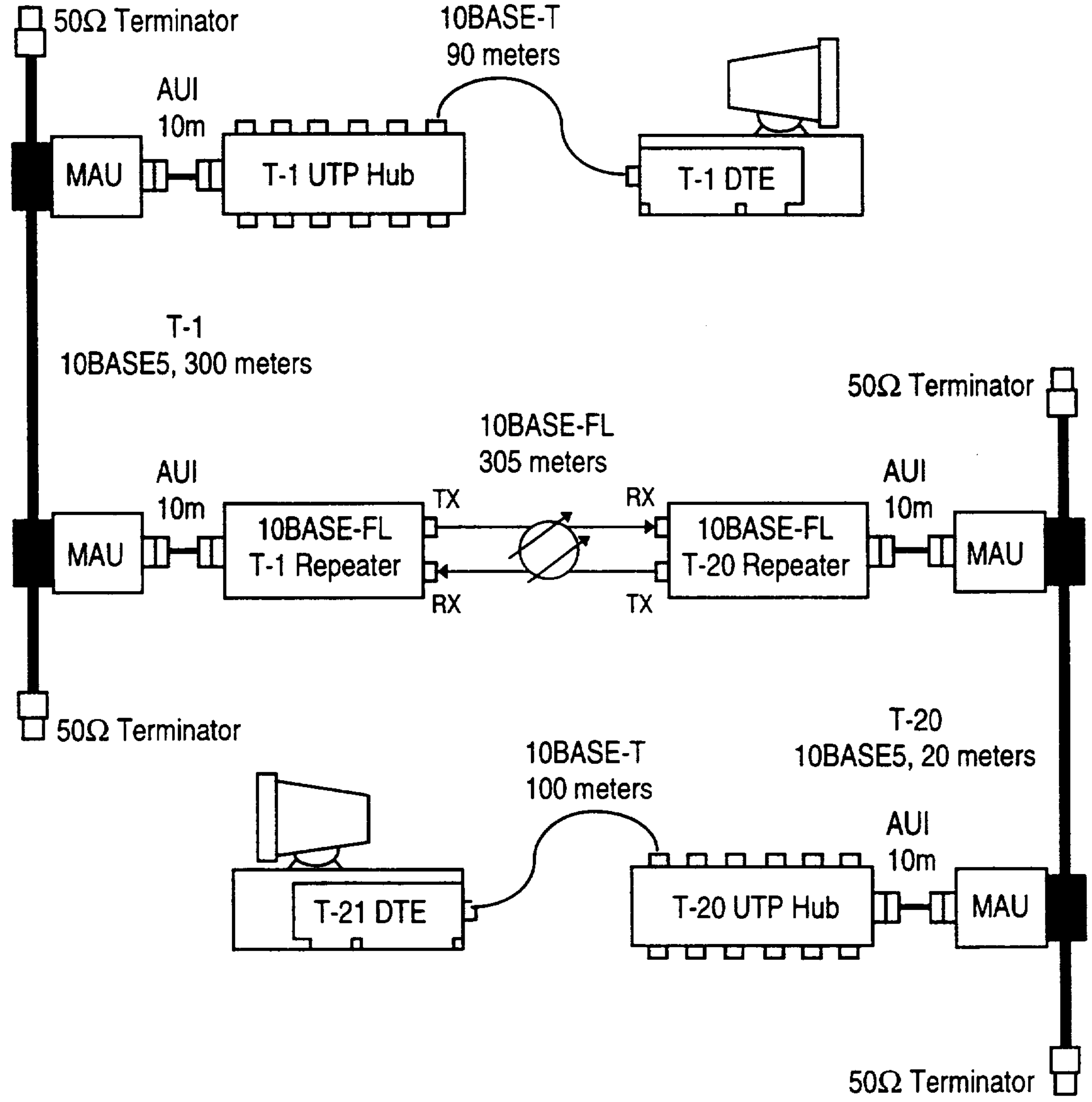


Figure 3-17

WSGT Worst-Case Round-Trip Delay Model

The STGT worst-case path is between a T-2 DTE and the T-4 Guard Shack DTE. They are both attached to a 10BASE-T end-segment which are connected to a 10BASE5 mid-segment. The 10BASE5 mixing segment is 260 meters long. Only three segments are involved. The longest T-2 10BASE-T cable is 160 meters long.

This cable exceeds the nominal longest recommended run for 10BASE-T; however, runs can be longer than 100 meters depending on the cable quality [39]. The maximum insertion loss for 10BASE-T is no more than 11.5 dB [40]. The 160 meter run consists of Category 5 cable which has lower attenuation than the standard Category 3 cable which enables it to successfully support the link. It can be calculated that Category 3 cable has about 1.7 dB of margin at 100 meters and Category 5 cable has 6.7 dB of margin at 100 meters. The 160 meter Category 5 cable run has 1.0 dB of margin from the 11.5 dB specification [41]. A model of this system is shown in Figure 3-18.

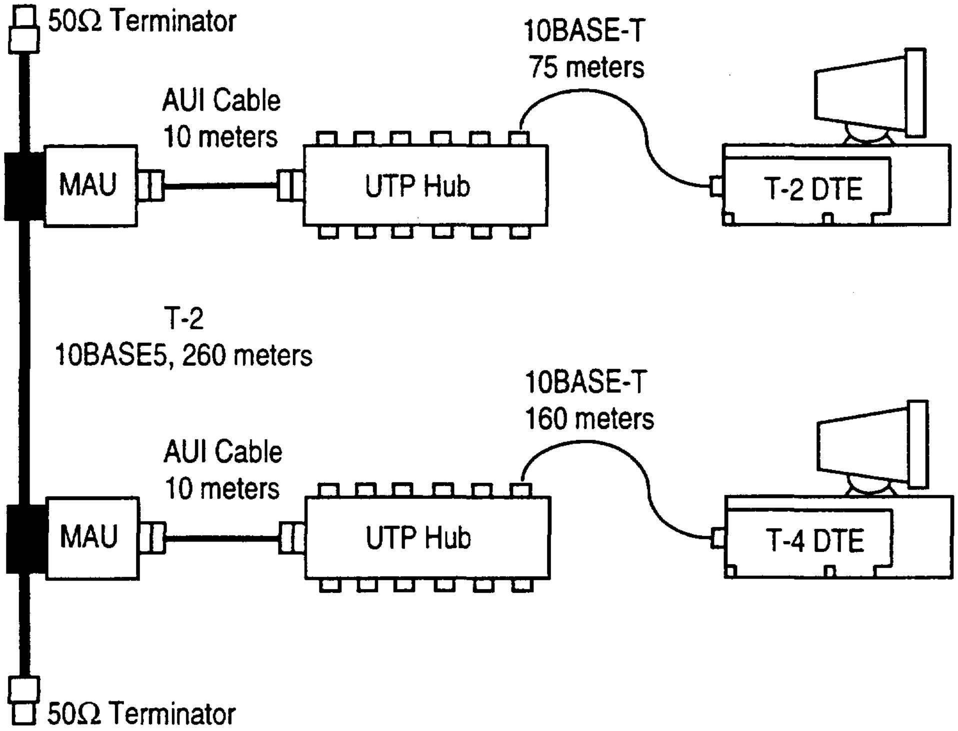


Figure 3-18

STGT Worst-Case Round-Trip Delay Model

The ETGT worst-case round-trip model has 10BASE2 end-segments connected by fiber optic repeaters over a 610 meter 10BASE-FL mid-segment. The 10BASE2 end-segment in T-1 is 90 meters long. The 10BASE2 end-segment in T-16 is 25 meters long. Figure 3-19 shows the ETGT worst-case round-trip configuration.

The single 10BASE2 segment (isolated by the router) in T-20 Logistics does not require round-trip analysis and, as a single segment, does not have interframe gap shrinkage. The STGT Power Plant has only two segments, a 10BASE5 and a 10BASE-T. This simple network also does not require analysis for round-trip delay or interframe gap shrinkage.

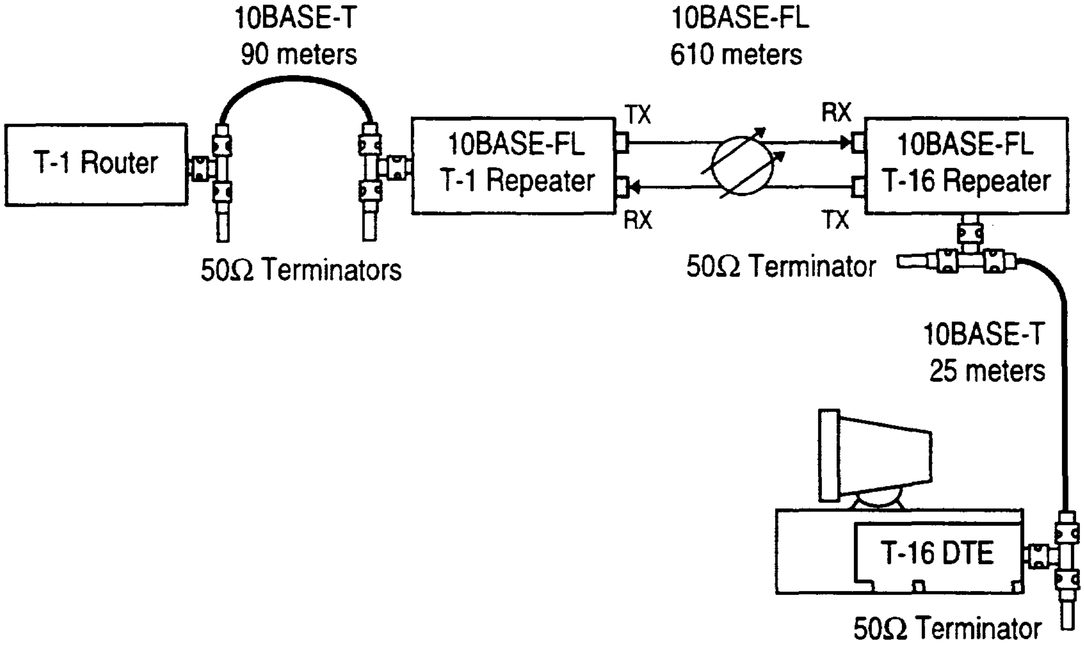


Figure 3-19

ETGT Worst-Case Round-Trip Delay Model

The Administration LAN interconnection from WSGT Building T-1 to STGT Building T-2 shown in Figure 3-9 is made using a pair of fiber optic Ethernet Campus Bridges [42] designed for full Ethernet bandwidth connectivity over long distances using singlemode fiber. The connectivity distance limit using this product is not restricted by the Ethernet specifications for slotTime and jamTime, but rather by the fiber optic loss budget [43]. Fiber has a round-trip delay time of 0.1 bit times per meter, so the 6,000 meter singlemode fiber optic cable run between WSGT and STGT would have a round-trip delay of 600 bit times, which is in excess of the specification. The manufacturer has used a proprietary technology to overcome the specification limitation. Had this technology been unavailable, the connection could have been made using fiber optic routers.

Routers are specifically designed for wide area networking using a higher level of protocol in the OSI stack and are not restricted by the maximum round-trip delay limitation for a local area network. The disadvantage to using a router is the slower data transfer rate. The maximum data transmission rate for a router is 2.048 Mbps, the European E-1 data transfer standard. The Ethernet Campus Bridges operate nearly five times faster at 10 Mbps.

Having found three worst-case models, they are examined for round-trip delay and interframe gap shrinkage by applying Tables 3-2 and 3-3. First, the separate left-end delay values are calculated so that the actual worst-case direction is determined. The model allows for 2 meter long AUI cables, so the calculation needs to account for the total extra AUI cable length. Then the mid-segment lengths are calculated. The results are summed to complete the total round-trip delay. Last, the interframe gap shrinkage is found. If each worst-case model has less than 570 bit times round-trip delay and an interframe gap shrinkage of 49 bit times or less, then the network topology is valid and will work according to IEEE 802.3 specifications.

3.6.4.1 Calculating Separate Left End Values

Two of the models have 10BASE-T end-segments and the other has 10BASE2 end-segments. They are the same type at each end. The delay per meter factor for 10BASE-T is 0.113 bit times per meter and the factor for 10BASE2 is 0.1026 bits times per meter. Table 3-4 summarizes the left-end calculations for the three worst-case models.

Table 3-4: Left-End Values for the WSC Models

Worst-Case Model	Left-End Length in meters	Times Media Factor	Length Delay in Bit Times	Add Base Delay Value	Total Delay in Bit Times
WSGT	90	0.113	10.17	15.25	25.42
	100	0.223	11.30	15.25	26.55
STGT	75	0.113	8.475	15.25	23.725
	160	0.113	18.08	15.25	33.33
ETGT	25	0.1026	2.54	11.75	14.29
	90	0.1026	9.234	11.75	20.984

In each case, the longer cable run has the longest delay, so the longest cable run will be used for the left-end segment in the analysis. The shorter cable run will be assigned to the right-end segment for analysis.

3.6.4.2 AUI Delay Value

The WSGT model has four AUI cables, each one is ten meters long. The model allows for 2-meter long cables and any over that is considered excess. The STGT model has two ten-meter long AUI cables. The delay factor for excess AUI cable length is 0.1026 bit times per meter. The ETGT model does not have any AUI cables. The 10BASE2 and 10BASE-FL segments attach directly to the router, repeaters, and DTE, so there is not any excess AUI delay for this model. Table 3-5 provides the excess AUI calculations which will be added in the complete analysis.

Table 3-5: Excess AUI Calculations for the WSC Models

WSC Worst-Case Model	**Excess AUI Cable Length in Meters**	**Times Media Factor in Bit Times/Meter**	**Total Excess AUI Delay in Bit Times**
WSGT	32	0.1026	3.2832
STGT	16	0.1026	1.6416
ETGT	0	0.1026	0

3.6.4.3 Calculating Middle-Segment Values

The middle-segment values for each model are calculated next. The WSGT model has three mid-segments: one that is comprised of 10BASE-FL media and two that are 10BASE5 media. The delay factor for 10BASE5 is 0.0866 bit times per meter and the delay factor for 10BASE-FL is 0.1 bit times per meter. Table 3-6 provides the mid-segment delay values for the three models.

Table 3-6: Middle-Segment Delay Values for the WSC Models

WSC Worst-Case Model	Mid-Segment Length in Meters	Times Media Factor	Length Delay in Bit Times	Add Base Delay Value	Total Delay in Bit Times
WSGT 10BASE5	300	0.0866	25.98	46.5	72.48
TSB T-20 10BASE 5	20	0.0866	1.732	46.5	48.232
WSGT to T-20 10BASE-FL	305	0.1	30.5	33.5	64.0
STGT 10BASE5	270	0.0866	23.382	46.5	69.882
WSGT to ETGT 10BASE-FL	610	0.1	61.0	33.5	94.5

3.6.4.4 Completing the Round-Trip Timing Calculation

The round-trip timing calculation is completed by calculating the right-end segment. This will be for the shorter length cable from the 10BASE2 or 10BASE-T segments in the model. The delay factors are the same previously used, but the added base value is higher. The right-end segment delay values are given in Table 3-7.

Table 3-7: Right-End Values for the WSC Models

Worst-Case Model	Right-End Length in meters	Times Media Factor	Length Delay in Bit Times	Add Base Delay Value	Total Delay in Bit Times
WSGT	90	0.113	10.17	165	175.17
STGT	75	0.113	8.475	165	173.475
ETGT	25	0.1026	2.54	156.5	159.04

3.6.4.5 Completing the Round-Trip Calculation for the WSC Models

The results from Tables 3-4, 3-5, 3-6, and 3-7 are then summed together for each of the worst-case models to obtain the round-trip delays. If the total for the model is less than 570 bit times, then the model meets the Ethernet timing specifications for one collision domain. The results are shown in Table 3-8.

Table 3-8: Total Round-Trip Delay for the WSC Worst-Case Models

WSC Worst-Case Model	Left-End Segment Delay	Excess AUI Cable Delay	Mid-Segment Delay	Right-End Segment Delay	Total Model Delay
WSGT	26.55	3.2832	72.48 48.232 64.0	175.17	389.7152
STGT	33.33	1.6416	173.475	173.475	278.3286
ETGT	20.984	0	159.04	159.04	274.524

All three worst-case collision domain models have total round-trip delay times that are less than 570 bit times, so they meet the specification for the timing requirement.

3.6.4.6 Finding the Interframe Gap Shrinkage for the WSC Models

In WSGT model, the transmitting end segment is 10BASE2 in either direction and there are two 10BASE5 mid-segments and one 10BASE-FL mid-segment. Then, the total interframe gap shrinkage is maximum at 49 bit times as calculated from the data provided in Table 3-3. This is the maximum interframe gap shrinkage allowable by the specification.

Table 3-9: WSGT Worst-Case Interframe Gap Shrinkage

WSGT Segment	Interframe Gap Shrinkage
Transmitting End - 10BASE2	16
Mid-Segment - 10BASE5	11
Mid-Segment - 10BASE-FL	11
Mid-Segment - 10BASE5	11
Total Interframe Gap Shrinkage	49

STGT has a 10BASE-T transmitting segment and a 10BASE5 mid-segment for a total interframe gap shrinkage of 21.5. ETGT has a 10BASE2 transmitting segment and a 10BASE-FL mid-segment for a total interframe gap shrinkage of 24. The WSC model interframe gap shrinkage is at the maximum value and the other models have interframe gap shrinkage values that are lower than the specification's maximum value.

These results conclusively show that the individual collision domains and the complete White Sands Complex Administration LAN meet the Ethernet configuration requirements of the IEEE 802.3 specification.

3.7 Internet Connectivity via the PSCN-I

The WSC Internet gateway was provided by Marshall Space Flight Center (MSFC) as part of the Program Support Communications Network - Internet (PSCN-I). This service provides a fractional T-1 bandwidth Internet connection (256 Kbps) to Goddard Space Flight Center (GSFC) and to the Jet Propulsion Laboratory (JPL). The service provides an Email server and access to the World Wide Web (WWW).

3.7.1 Internet Connectivity Configuration

The WSC Internet connection is part of a larger restricted Internet connectivity plan [44] for NASA facilities at Goddard Space Flight Center (GSFC); Merritt Island (MIL); Ponce de León (PDL); Bermuda (BDA); the Jet Propulsion Laboratory (JPL); and at a major subcontractor's facility, Allied Technical Services Corporation (ATSC) in Columbia, Maryland. The general configuration of this larger administration communications structure is shown in Figure 3-20.

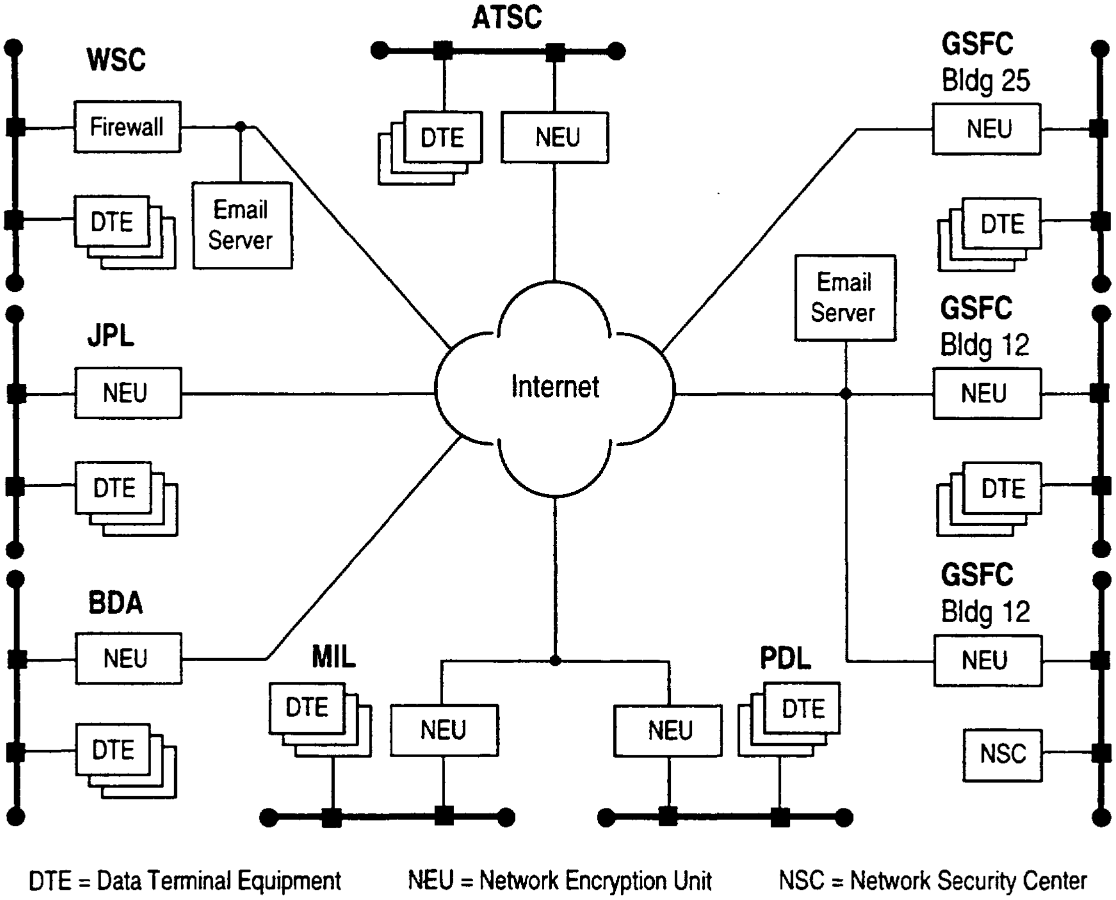


Figure 3-20

Ground Network/Space Network Restricted Internet Gateway

To prevent undesired intrusion into the various administrative LANs by unauthorized personnel, the NASA facility LANs are equipped with either a router configured as a security firewall like the one at WSC or with a network encryption unit which is used at most of the other facilities. The Email servers are external to the security devices to allow open Email access throughout the Internet community.

The WSC Administration LAN has been configured into the Internet via two different gateways for redundancy in case of component or circuit failure. One gateway is at the Second TDRS Ground Terminal and the other is at the White Sands Test Facility. Each of the gateways provides a T-1 circuit to the telecommunications common carrier, FTS-2000. The T-1 circuits are subrated for a mixture of different services including the Internet connections and video teleconferencing. A simplified drawing of the PSCN-I gateway installation is shown in Figure 3-21.

The WSC Administration LAN is attached to a router which has been configured to filter packets so that only approved traffic can transit the router. This setup is known as a "firewall," and it provides a level of network security from unauthorized access. The firewall outputs to a multiport MAU which is connected to the Email server computer and also to a fiber optic MAU which connects the Administration LAN to the PSCN-I router which is located some distance away near the common carrier equipment racks. The PSCN-I router has two outputs. The first one is a 256 Kbps serial output to a multiplexer. The multiplexer mixes the 256 Kbps Administration LAN signal with a ½ T-1 rate (768 Kbps) video teleconferencing signal and outputs a composite T-1 telecommunications signal to the customer service

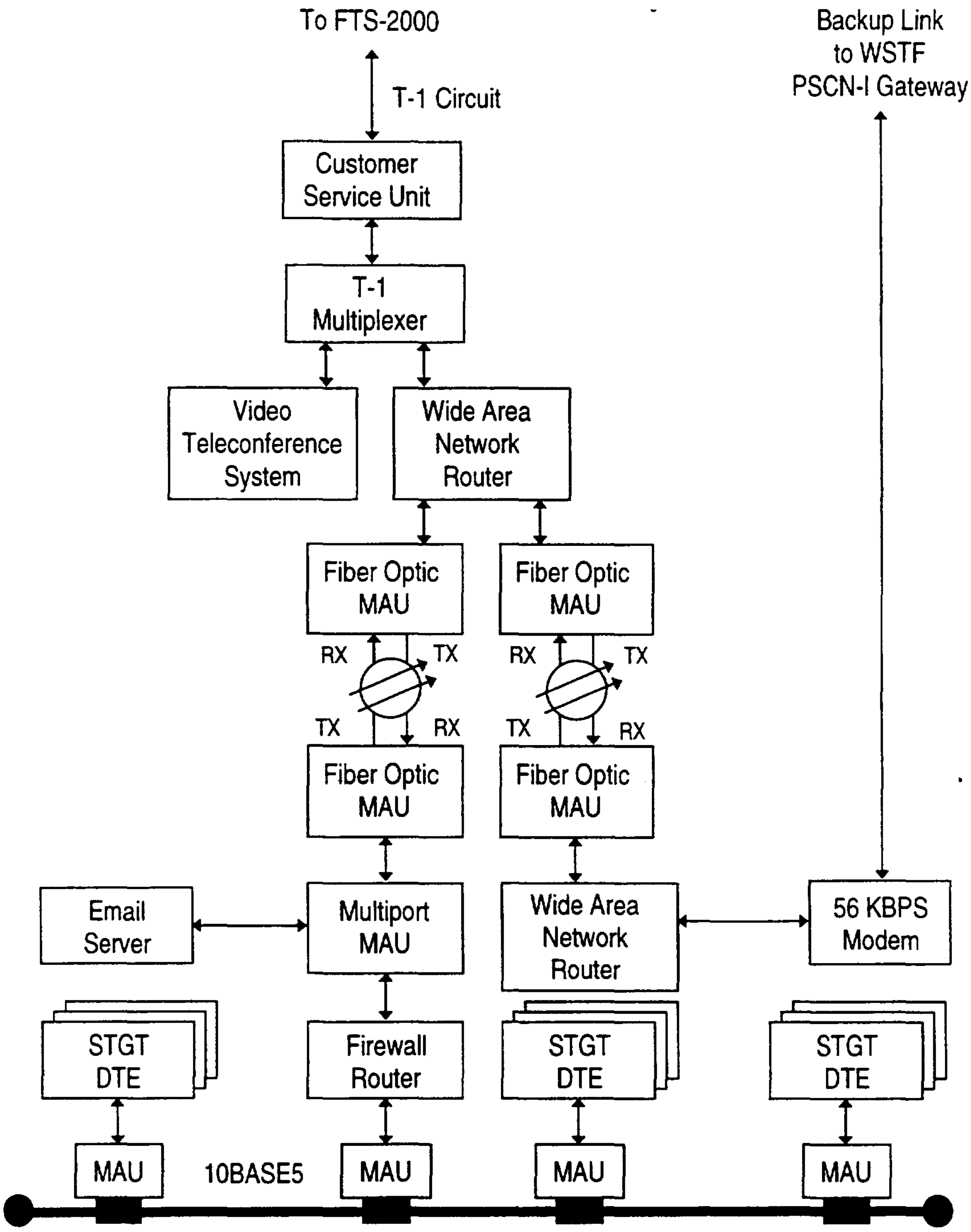


Figure 3-21

A Simplified Drawing of the WSC PSCN-I Gateway unit (CSU) which is the demarcation point between WSC and FTS-2000, the common carrier. The second PSCN-I router output is another fiber optic path to the backup router. The backup router communicates with another very similar PSCN-I gateway at WSTF via a 56 Kbps modem over copper lines. This is a complex installation as can be seen in the installation detail drawing provided as Figure 3-22. The system can be remotely configured via access modems over ordinary telephone circuits. Remote configuration is performed by the PSCN-I network administrator at MSFC in Huntsville, Alabama.

3.7.2 Internet Performance Bandwidth

The Internet connection is established at 256 Kbps out of the 1.544 Mbps T-1 bandwidth. This bandwidth was selected based on an estimate of the traffic expected over the Internet. It also provided some expansion room within the T-1 circuit should the traffic level increase beyond the capacity of 256 Kbps. The T-1 circuit has the equivalent of seven 56 Kbps individual telephone circuits in reserve, so the Internet bandwidth could be incremented by a factor of two to 512 Kbps, the next available step. This has not yet been necessary.

Monthly records of the Internet utilization are kept by the PSCN-I network administrator. The records for the months of May, June, and July 1996 have been examined for traffic patterns and peak traffic levels. As can be seen in the attached data in Figure 3-23, the traffic pattern is generally well within a reasonable margin of the 256 Kbps bandwidth with the peak at just under 30% utilization. This is an acceptable level of performance for this kind of installation.

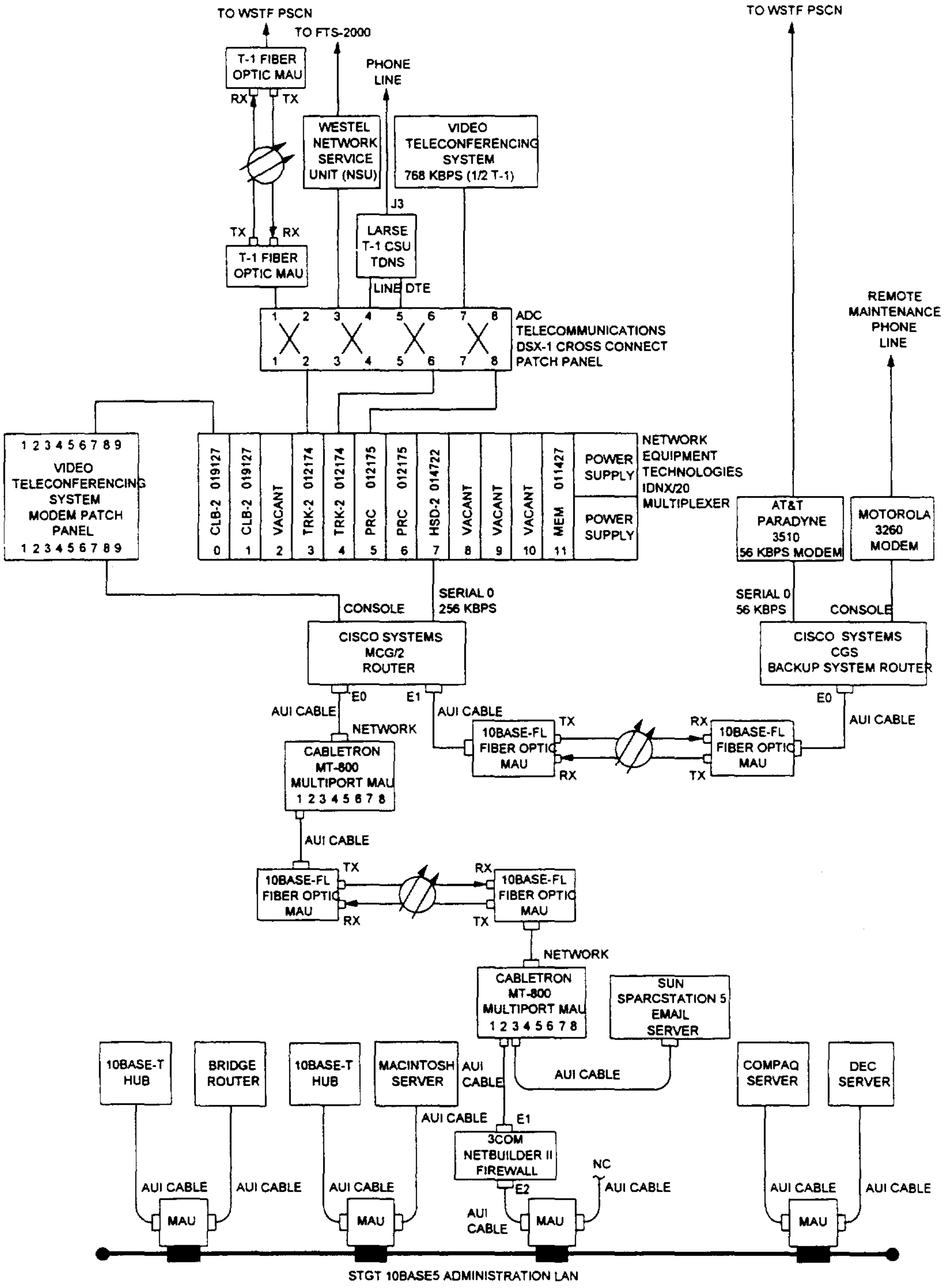


Figure 3-22

PSCN-I Installation Details

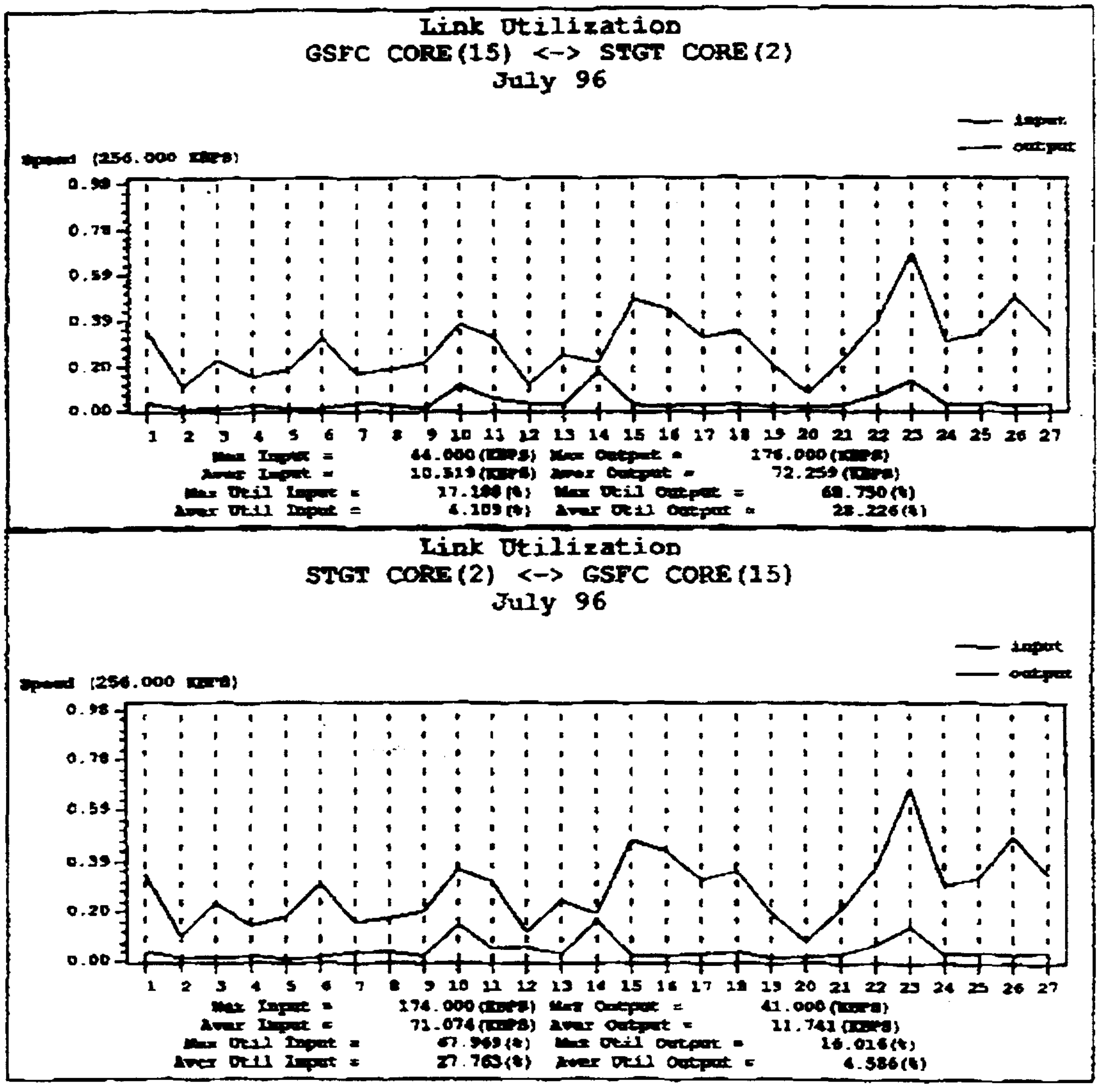


Figure 3-23

WSC PSCN-I Bandwidth Utilization for July 1996

3.8 Fiber Optic Installation Performance Analysis

The fiber optic links require analysis of performance parameters other than the round-trip delay and the interframe gap shrinkage analysis. The optical power budget must be examined to determine if the link has sufficient margin for current operation as well as for future repairs and aging. The multimode fiber links require analysis of the bandwidth to length margin. This analysis is not required for the singlemode links since their data bandwidth is so high as to be automatically acceptable in a campus-size installation such as the one at WSC.

3.8.1 Optical Power Budget Analysis

There are three optical fiber links that will be analyzed: 1) the 10BASE-FL link between T-1 and T-16, 2) the 10BASE-FL link between T-1 and T-20, and 3) the singlemode link between T-1 and T-2. The optical source is usually an LED or it may be a laser source. The launch power for an LED is nominally much less than for a laser and it can drive a correspondingly lower optical loss budget. The LED source is typically used with multimode fiber installations and lasers (which also have a more narrow beamwidth) are used with singlemode fibers.

There are two typical different types of receiver devices. One is the positive-intrinsic negative (PIN) diode and the other is an avalanche photodiode (APD). The APD has higher gain and is more sensitive in its response to light levels and is typically used where its multiplication factor is required while the PIN diode has high linearity and is used where that is an advantage, especially in linear analog systems.

3.8.1.1 WSGT T-1 to ETGT T-16 Link Optical Power Budget

This link consists of multimode fiber. The length is 610 meters. The fiber has an attenuation specification of 4.30 dB per kilometer at a wavelength of 850 nm. The installation follows the diagram presented as Figure 3-7. It has a pair of jumper cables at each end for transmission and reception. These cables are two meters long and have similar attenuation characteristics as the bulk fiber. There are two ST connectors associated with the jumpers, one at each end. The bulk cable is spliced to pigtails that are 3.5 meters long. The LED source transmitter launches -16 dBm and the reception sensitivity is -30 dBm with saturation at -15 dBm. Table 3-10 provides a tabular calculation of the optical power budget for this link.

Table 3-10: Optical Power Budget for the WSGT T-1 to ETGT T-16 Link

Component	**Factor**	**Number or Length**	**Total Gain/Loss, dB**
Source	-	1	-16.0
Connector	0.5 each	1	<0.5>
Jumper Cable	4.3dB/km	2 meters	<0.0086>
Connector	0.5 each	1	<0.5>
Pigtail	4.3 dB/km	3.5 meters	<0.01505>
Splice	0.5 each	1	<0.5>
Bulk Fiber	4.3 dB/km	610 meters	<2.623>
Splice	0.5	1	<0.5>
Pigtail	4.3 dB/km	3.5 meters	<0.01505>
Connector	0.5 each	1	<0.5>
Jumper Cable	4.3 dB/km	2	<0.0086>
Connector	0.5 each	1	<0.5>
Total Budget	-	-	-21.6603
Receiver Sensitivity	-	1	-30.0
Optical Margin	-	-	8.3397

3.8.1.2 WSGT T-1 to TSB T-20 Link Optical Power Budget

This link is also multimode fiber. The length is 305 meters. The fiber has the same attenuation specification of 4.30 dB per kilometer for a wavelength of 850 nm. This installation also follows the diagram presented as Figure 3-7 and except for the length of the bulk fiber, it is identical with the installation in Section 3.8.1.1. Table 3-11 provides a tabular calculation of the optical power budget for this link.

Table 3-11: Optical Power Budget for the WSGT T-1 to TSB T-20 Link

Component	**Factor**	**Number or Length**	**Total Gain/Loss, dB**
Source	-	1	-16.0
Connector	0.5 each	1	<0.5>
Jumper Cable	4.3dB/km	2 meters	<0.0086>
Connector	0.5 each	1	<0.5>
Pigtail	4.3 dB/km	3.5 meters	<0.01505>
Splice	0.5 each	1	<0.5>
Bulk Fiber	4.3 dB/km	305 meters	<1.3115>
Splice	0.5	1	<0.5>
Pigtail	4.3 dB/km	3.5 meters	<0.01505>
Connector	0.5 each	1	<0.5>
Jumper Cable	4.3 dB/km	2	<0.0086>
Connector	0.5 each	1	<0.5>
Total Budget	-	-	-20.3488
Receiver Sensitivity	-	1	-30.0
Optical Margin	-	-	9.6512

3.8.1.3 WSGT T-1 to STGT T-2 Link Optical Power Budget

This link consists of singlemode fiber. The length of the main section is 6,000 meters. The fiber has an attenuation specification of 0.50 dB per kilometer for a wavelength of 1310 nm. Jumper cables have an attenuation factor of 1 dB/km. The connectors have lower loss than the equivalent multimode connectors at about 0.2 dB.

Splices were held to a specification of 0.1 dB or better. This installation is similar to the T-1 to T-20 and T-1 to T-16 optical links except it has two additional 125 meter runs of fiber to bring it from the ground control equipment (GCE) rooms at each facility to an administration area where it can be attached to the 10BASE-FL medium access units. The attenuation factor for the 125 meter runs is 1.0 dB/km. A diagram of the WSGT T-1 to STGT T-2 fiber optic link installation is shown as Figure 3-24.

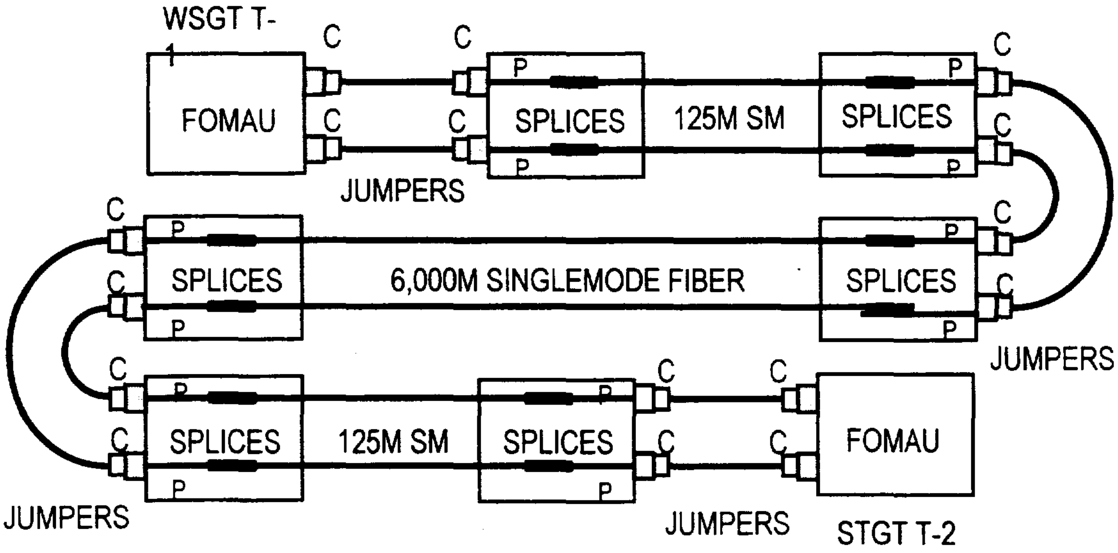


Figure 3-24

WSGT T-1 to STGT T-2 Fiber Optic Link

The optical source is a special, enhanced type of LED called an edge LED (ELED) that can couple to the narrow acceptance angle and very small numerical aperture (NA = 0.06) of the singlemode fiber. The ELED launches about -17 dBm. The receiver has a sensitivity of -34 dBm, so this system has a total optical loss budget of 17 dBm. The optical power budget is given in Table 3-12.

Table 3-12: Optical Power Budget for the WSGT T-1 to STGT T-2 Link

Component	Factor	Number or Length	Total Gain/Loss, dB
Source	-	1	-17.0
Connector		1	<0.2>
Jumper Cable	1.0dB/km	2 meters	<0.002>
Connector	0.2 each	1	<0.2>
Pigtail	1.0 dB/km	3.5 meters	<0.0035>
Splice	0.1 each	1	<0.1>
Bulk Fiber	1.0 dB/km	125 meters	<0.125>
Splice	0.1 each	1	<0.1>
Pigtail	1.0 dB/km	3.5 meters	<0.0035>
Connector	0.2 each	1	<0.2>
Jumper Cable	1.0 dB/km	2 meters	<0.002>
Connector	0.2 each	1	<0.2>
Pigtail	1.0 dB/km	3.5 meters	<0.0035>
Splice	0.1 each	1	<0.1>
Bulk Fiber	0.5 dB/km	6,000 meters	<3.0>
Splice	0.1 each	1	<0.1>
Pigtail	1.0 dB/km	3.5 meters	<0.0035>
Connector	0.2 each	1	<0.2>
Jumper Cable	1.0 dB/km	2 meters	<0.002>
Connector	0.2 each	1	<0.2>
Pigtail	1.0 dB/km	3.5 meters	<0.0035>
Splice	0.1 each	1	<0.1>
Bulk Fiber	1.0 dB/km	125 meters	<0.125>
Splice	0.1 each	1	<0.1>
Pigtail	1.0 dB/km	3.5 meters	<0.0035>
Connector	0.2 each	1	<0.2>
Jumper Cable	1.0 dB/km	2 meters	<0.002>
Connector	0.2 each	1	<0.2>
Total Budget	-	-	-22.479
Receiver Sensitivity	-	1	-34.0
Optical Margin	-	-	11.521

As can be seen from the optical budget tables, all three optical fiber links have sufficient margin for correct operation as well as for degradation due to aging or from maintenance repairs. Optical testing in the system confirms these basic margins.

3.8.2 Optical Bandwidth Performance Analysis

The overall optical link bandwidth is determined by four factors: optical source bandwidth, multimode or modal dispersion in the fiber, chromatic dispersion in the fiber, and the receiver bandwidth [45]. Modal dispersion does not occur in singlemode links because singlemode fiber only supports one electromagnetic wave propagation mode. The effects of these factors can be modeled as Gaussian filters as shown in Figure 3-25:

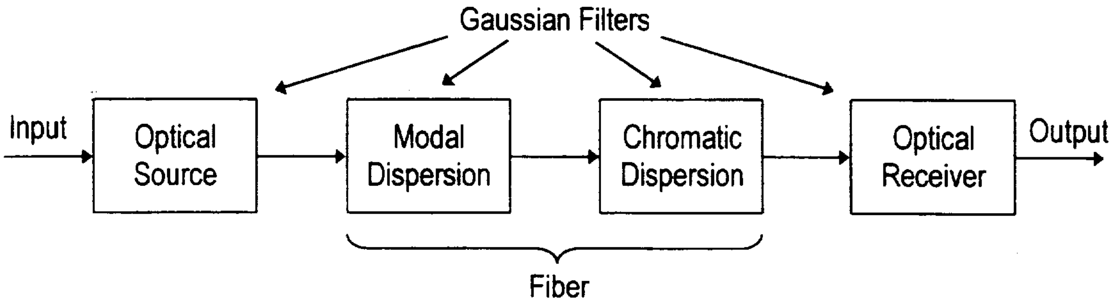


Figure 3-25

Fiber Optic Link Bandwidth Model

The bandwidth of either the optical source or receiver can be estimated by the following equation:

$$f_{el} = \frac{0.34}{t_r} \tag{3.1}$$

Where f_{el} is the electrical half-power bandwidth, and t_r is the 10% to 90% rise time of either the source or the receiver.

The optical half-power bandwidth is related to the electrical half-power bandwidth by the relation:

■ $$f_{el} = 0.707 \times f_o \tag{3.2}$$

Where f_o is the optical half-power bandwidth.

The modal dispersion, f_{modal}, (for multimode fibers only) is the electrical bandwidth divided by the fiber length in kilometers, l_{km}.

■ $$f_{modal} = \frac{f_{el}}{l_{km}} \tag{3.3}$$

The chromatic dispersion of the fiber is due primarily to material dispersion. Material dispersion is a function of the fiber design. Most fiber is designed for very low dispersion in the vicinity of 1310 nm and will have higher values for other transmitted wavelengths [47]. The normalized value is 95 ps/(nm km) for fibers at the 850 nm wavelength. The root-mean-square (rms) dispersion parameter, $\sigma_{material}$, associated with the material effects of the multimode links can be calculated from equation 3.4:

■ $$\sigma_{material} = \frac{95\ ps}{nm \times km} \times rms\ linewidth_{nm} \times l_{km} \tag{3.4}$$

For fibers at 1310 nm wavelength, the normalized dispersion factor is much smaller, about -5 ps/(nm km). The negative number refers to the direction in frequency of the dispersion and is not important in the rest of the calculations. The rms dispersion parameter, $\sigma_{material}$, associated with the material effects of the singlemode link can be calculated by:

■ $$\sigma_{material} = \frac{5\ ps}{nm \times km} \times rms\ linewidth_{nm} \times l_{km} \qquad (3.5)$$

To obtain the rms linewidth in nanometers, it is necessary to know the full width half maximum (FWHM) linewidth which is usually specified by the manufacturer of the source. For this application, there is a maximum FWHM linewidth in the IEEE 10BASE-FL specification. The value for the edge LED used in the singlemode campus bridge was provided by the manufacturer. The value is provided along with the other optical design parameters in Table 3-13. Equation 3.6 is used to obtain the rms linewidth from the FWHM linewidth and a conversion factor.

■ $$rms\ linewidth = \frac{FWHM\ linewidth}{2.36} \qquad (3.6)$$

The material dispersion bandwidth can be calculated from the rms material dispersion factor, $\sigma_{material}$, and a constant as shown in equation 3.7.

■ $$f_{material} = \frac{0.133}{\sigma_{material}} \qquad (3.7)$$

Once the various bandwidth components have been calculated, the overall system bandwidth can be calculated from equation 3.8:

- $$f_s = \sqrt{\frac{1}{1/f_{source}^2 + 1/f_{modal}^2 + 1/f_{material}^2 + 1/f_{receiver}^2}} \qquad (3.8)$$

The fiber optic MAUs switch the source on and off to send non-return to zero (NRZ) coded data. From the calculated system optical bandwidth the maximum data rate for on-off keyed NRZ data transmission over the link can be estimated from equation 3.9:

- $$R_b \cong \frac{0.3}{\sigma_s} \cong 2.25 \times f_s \qquad (3.9)$$

The above tools are used to calculate the system bandwidth for the two multimode optical fiber links and the one singlemode optical fiber link used at WSC. A data set of the parameters needed for the calculations is given in Table 3-13. Several of the parameters are specified by the IEEE 802.3 specification and others are manufacturer's data.

Table 3-13: System Parameters for Fiber Optic Link Bandwidth Calculations

Parameter	**Value**
Source Rise Time	10 nanoseconds
Singlemode Source FWHM linewidth	1.5 nanometers
Multimode Source FWHM linewidth	75 nanometers
Receiver Rise Time	10 nanoseconds
Multimode Fiber Bandwidth	160 MHz kilometers
Multimode Fiber Length (T-1 to T-16)	0.61 kilometers
Multimode Fiber Length (T-1 to T-20)	0.305 kilometers
Singlemode Fiber Length (T-1 to T-2)	6.25 kilometers

Using the rise time for the source and equation 3.1 the electrical half-power bandwidth for the source is calculated to be 34 MHz. From that value and equation 3.2, the optical half-power bandwidth can be found to be 48 MHz km. For the two multimode fiber runs, the modal dispersion bandwidth can be found from equation 3.3 to be 78.7 MHz for the longer run from T-1 to T-16 and 157.4 MHz for the shorter run from T-1 to T-20. The modal dispersion parameter is not applicable to singlemode fiber runs.

The rms source linewidth is next calculated from the FWHM linewidth of the optical sources using equation 3.6. For the multimode source, the rms linewidth is 31.8 nm. For the singlemode source, the rms linewidth is 0.64 nm. Now the rms material dispersion parameters for the two types of fiber can be calculated. From equation 3.4, the 610 meter multimode fiber run has a $\sigma_{material}$ of 1.84 ns. For the 305 meter multimode fiber run, $\sigma_{material}$ is 0.92 ns. From equation 3.5, the 6.25 kilometer singlemode fiber run has a $\sigma_{material}$ of 0.02 ns. The chromatic dispersion bandwidth of the fibers is calculated using equation 3.7. The 610 meter multimode run has an $f_{material}$ of 72.3 MHz. The 305 meter multimode run has an $f_{material}$ of 144.6 MHz and the 6.25 kilometer singlemode fiber link has an $f_{material}$ of 6.65 GHz. It can easily be seen that the singlemode fiber has a much higher bandwidth capability from this factor than does the multimode fiber. The shorter length of multimode is also better than the longer length.

Receivers usually have a faster rise time than the source; however, without manufacturer's data to back this up, the IEEE specification [46] of 10 ns will be used. The electrical half-power bandwidth of the receiver is the same as calculated for the source and is 34 MHz. The next step is to combine the bandwidth parameters using equation 3.8 to obtain the system bandwidth for each of the fiber optic runs.

- $f_{MM1} = \sqrt{\dfrac{1}{{}^{1}\!/_{34\,MHz^2} + {}^{1}\!/_{78.7\,MHz^2} + {}^{1}\!/_{72.3\,MHz^2} + {}^{1}\!/_{34\,MHz^2}}}$
- $f_{MM1} = 21.91\,MHz$ for the 610 meter link between T-1 and T-16
- $f_{MM2} = \sqrt{\dfrac{1}{{}^{1}\!/_{34\,MHz^2} + {}^{1}\!/_{157.4\,MHz^2} + {}^{1}\!/_{1.44.6\,GHz^2} + {}^{1}\!/_{34\,MHz^2}}}$
- $f_{MM2} = 22.71\,MHz$ for the 305 meter link between T-1 and T-20
- $f_{SM} = \sqrt{\dfrac{1}{{}^{1}\!/_{34\,MHz^2} + {}^{1}\!/_{6.65\,GHz^2} + {}^{1}\!/_{34\,MHz^2}}}$
- $f_{SM} = 24.04\,MHz$ for the 6.25 km link between T-1 and T-2

From the above results, we see that the lowest optical system bandwidth is for the longest run of multimode fiber and that the highest optical system bandwidth is for the singlemode run. The dominating factor in all these calculations is the bandwidth of the optical source and detector. The capability of the singlemode fiber far exceeds the system bandwidth calculated above; however, this calculated bandwidth is based upon the rise time specification for IEEE 802.3. The system bandwidths are in any case over twice that required for the 10 MHz Ethernet transmission carrier frequency.

For completeness, the maximum bit rate for an on-off keyed NRZ data transmission is calculated using equation 3.8. The maximum bit rate is higher than the nominal Ethernet bit rate of 10 Mbps.

- $R_{bMM1} \cong 2.25 \times 21.9\ MHz = 49.3\ Mbps$ 610m MM link maximum bit rate
- $R_{bMM2} \cong 2.25 \times 22.7\ MHz = 51.1\ Mbps$ 305m MM link maximum bit rate
- $R_{bSM} \cong 2.25 \times 24.0\ MHz = 54.0\ Mbps$ 6.25km SM link maximum bit rate

Thus, the three WSC fiber optical Ethernet links can easily support the intended Ethernet application at 10 Mbps. With suitable drivers and receivers, they are also capable of supporting the newer 100BASE-F specification. The dominating factor in fiber bandwidth and maximum bit rate (when the optical sources and receivers are very fast) is modal dispersion for the multimode fiber and chromatic dispersion for the singlemode fiber. Optical power attenuation becomes an important design factor for multimode fibers at about six kilometers total length and at about 45 kilometers total length for singlemode fibers.

4.0 DISCUSSION AND CONCLUSIONS

An Administration Local Area Network has been designed, analyzed, installed, and tested at the NASA White Sands Complex: It has features of local, campus, and wide area networks. The WSC network design incorporates the ISO model for Open Systems Interconnect using IEEE 802.3 Ethernet for the Physical and Data Link layers. The *de facto* standard TCP/IP is used for the Network and Transport layers. The Session, Presentation, and Application layers are provided by commercial off-the-shelf software packages.

Each of the several facilities at WSC is provided a separate Ethernet collision domain and these are interconnected by routers. Analysis shows that each of the domains and the overall configuration meets the configuration guidelines for multi-segment installations provided in the IEEE specification for carrier sense multiple access with collision detection networks. The remote facilities are interconnected by optical fiber links except for the STGT T-2 to STGT T-3 Power Plant building connection. This connection is made using a backbone 10BASE5 coaxial cable. The optical links have been analyzed and shown to provide more than adequate data bandwidth and attenuation characteristics for this application. Independent optical testing provides equivalent results and confirms the analysis.

An Internet gateway has been provided with a Class C IP address space of 256 addresses. This provides IP addresses for up to 256 servers and users. The address space currently is approximately 80% utilized. With current trends toward lower staffing profiles, this address space is anticipated to be adequate for the foreseeable future. The provided Internet bandwidth of 256 Kbps has also been monitored for utilization and has, over a three month period, shown an average utilization rate at about 30 percent with peak utilization of under 70 percent. This is adequate for current needs; however, an expansion capability to 512 Kbps exists within the current Internet connection T-1 circuit. The circuit is shared with a video teleconferencing system that uses half the capacity (768 Kbps). Another 56 Kbps circuit in the T-1 aggregate bandwidth is used for a teletype service and the remaining bandwidth is unused and held in reserve.

The Administration LAN is a contemporary office management system that provides a variety of services including: Email; on-line logistics and maintenance data bases; electronic copies of engineering changes and local operating procedures; facilities maintenance database and real-time power monitoring; world wide web access, and a broadcast forum for important meeting notices and minutes.

As time progresses, it will become desirable to migrate the Administration LAN to the new fast Ethernet standard at 100 Mbps. The fiber interfacility links will support 100BASE-F with changes only to the fiber medium attachment units for the higher data rates. Most of the unshielded twisted pair installations are installed with Category 5 cable and can support 100BASE-T with a change to the network interface card. The very long run to the T-4 guard shack may not work at 100 Mbps; however, it is possible and sensible to mix 10 Mbps and 100 Mbps segments as they are needed. Most of the new fast Ethernet hubs will support mixed rates. Some of the existing 10BASE-T connections were made using older Category 3 telephone cable. These will need to be upgraded to Category 5 cable runs if the faster connection speed is required at those locations. They can be upgraded on a case-by-case basis.

All of the coaxial segments, whether they are 10BASE5 or 10BASE2, will require upgrade either to 100BASE-T or 100BASE-F to support fast Ethernet. The relative cost differential favors the upgrade to 100BASE-T. It is not anticipated that such an upgrade will be required within the next five to seven years. After that time, transfer of large files involving complex graphics will become more commonplace and the 10 Mbps bandwidth of standard Ethernet will become inadequate to support the traffic. The network will slow down and become a throughput limited system.

The transition from standard Ethernet to fast Ethernet for higher data rates and large file transfers will probably coincide with migration of the Internet from T-1 and T-3 (44.736 Mbps) asynchronous circuits to synchronous optical network (SONET) circuits operating at much higher data rates using optical carrier levels OC-1 (51.840 Mbps), OC-3 (155.520 Mbps), and higher. The future Internet will use broadband Integrated Services Digital Network (ISDN) and a data transport technology known as Asynchronous Transfer Mode (ATM) [48].

ATM promises the advantage of using telecommunications bandwidth more efficiently and providing the customer with bandwidth-on-demand access and billing. This would be a major advantage over the current tariff structure of purchasing a circuit for the peak bandwidth required, 24-hours a day, seven-days a week even though the circuit is used only occasionally to full capacity.

NASA has plans to migrate their space science data transfer from 4800-bit packet transport over common carrier domestic satellite links to Internet Protocol packet transport over terrestrial fiber links [49]. A follow-on plan calls for using ATM over terrestrial SONET links for this same purpose. It can be concluded that migration of the administration function to this same technology will follow in due course. NASA is taking the "on-ramp" to the federal "information super highway."

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