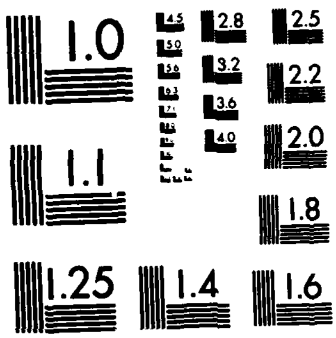
AD-A138 604 LOCAL NETWORK WIDEBAND INTERCONNECTION ALTERNATIVES(U) 1/1
MITRE CORP BEDFORD MA K ERAT ET AL. JAN 84 MTR-8563
ESD-TR-83-222 F19628-82-C-0001

UNCLASSIFIED F/G 17/2 NL

END
FILMED
4-84
DTIC


1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

ESD-TR-83-222 MTR-8563

(12)

LOCAL NETWORK WIDEBAND INTERCONNECTION ALTERNATIVES

By
K. ERAT
J. P. WORTHLEY

JANUARY 1984

Prepared for
DEPUTY FOR MISSION SYSTEMS
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Hanscom Air Force Base, Massachusetts

Project No. 4790
Prepared by
THE MITRE CORPORATION
Bedford, Massachusetts
Contract No. F19628-82-C-0001

REVIEW AND APPROVAL

This technical report has been reviewed and is approved for publication.

JONATHAN S. KATZ, Lt Col, USAF
Joint Program Director, AFLANSPO
Directorate of Information Systems

C. D. RUSSELL, Capt, USAF
Chief, Engineering & Design Branch,
AFLANSPO

FOR THE COMMANDER

ROBERT J. KENT
Director, Information Systems
Deputy for Mission Systems

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

AD A 137 ...

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE:

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): MTR-8563, ESD-TR-83-222

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: The MITRE Corporation

6b. OFFICE SYMBOL (If applicable):

6c. ADDRESS (City, State and ZIP Code): Burlington Road, Bedford, MA 01730

7a. NAME OF MONITORING ORGANIZATION:

7b. ADDRESS (City, State and ZIP Code):

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Deputy for Mission Systems

8b. OFFICE SYMBOL (If applicable): OCH

8c. ADDRESS (City, State and ZIP Code): Electronic Systems Division, AFSC, Hanscom AFB, MA 01731

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F19628-82-C-0001

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
	4790		

11. TITLE (Include Security Classification): Local Network Wideband Interconnection Alternatives

12. PERSONAL AUTHOR(S): K. Erat, J. P. Worthley

13a. TYPE OF REPORT: Final Report

13b. TIME COVERED: FROM ______ TO ______

14. DATE OF REPORT (Yr., Mo., Day): 1984 January

15. PAGE COUNT: 78

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Data Transmission; Local Area Networks; Satellite Communications

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Broadband local area networks are being acquired throughout the Air Force. This report addresses alternatives for interconnecting these networks. These alternatives support both data transmission at rates greater than 1.5 Mbps and two standard television channels.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☒ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL: Susan R. Gilbert

22b. TELEPHONE NUMBER (Include Area Code): (617) 271-8088

22c. OFFICE SYMBOL:

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

ACKNOWLEDGMENT

The authors would like to thank their MITRE colleagues, the military and civilian staff at Hanscom AFB and MIT/Lincoln Labs, and the many vendors that were surveyed for their time and cooperation in providing information for this report.

This document has been prepared by The MITRE Corporation under Project 4790, Contract F19628-82-C-0001. The contract is sponsored by the Electronic Systems Division, Air Force Systems Command, Hanscom Air Force Base, Massachusetts.

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (Concluded)

SECTION 1

INTRODUCTION

The Air Force has begun installing local area networks to provide wideband data communications for office automation and distributed processing applications. Broadband networks can provide channels for voice and video as well as data communications by frequency division multiplexing techniques (FDM). By 1990 local networks will exist at many Air Force bases throughout the United States and overseas.

If these networks were interconnected, data, voice and video communications could be supported on a broader scale than previously possible. This report addresses alternatives for such interconnections. Alternatives considered will support data transmission at rates greater than 1.5 Mbps and two standard televison channels.

1.1 SCOPE

Interconnection of local area networks within the continental United States is addressed. The cost, performance, and practical considerations of short- and long-haul wideband interconnection alternatives for these networks are analyzed. Media options are emphasized. Recommendations are made for alternatives that will maintain the reliability, efficiency, and throughput of the connected networks.

To derive specific cost information for the alternatives considered, four sites are examined which have potential requirements for short- and long-haul wideband communications:

a. MITRE Corporation, Bedford, MA
b. Electronic Systems Division (ESD), Hanscom AFB, Bedford, MA
c. Headquarters, Air Force Systems Command (Hq. AFSC), Andrews AFB, Washingon, DC
d. Space Division, Los Angeles (El Segundo), CA

Broadband networks are now in operation at the first three locations; a network at the Space Division is postulated so that cost information can be shown for a transcontinental link. Costs and media recommendations for interconnecting other networks will differ, depending upon distance, topographical, environmental and administrative factors. However, the methodology for deriving and evaluating alternatives would be similar.

1.2 ORGANIZATION

Short-haul wideband alternatives suitable for interconnecting the MITRE and ESD networks are addressed in section 2. Long-haul wideband alternatives for interconnecting the ESD, Headquarters AFSC and Space Division networks are addressed in section 3. Required interface equipment is discussed in section 4. Finally, conclusions and recommendations are summarized in section 5.

SECTION 2

SHORT-HAUL ALTERNATIVES

Several media alternatives exist for interconnecting the ESD and MITRE networks, which are separated by a line-of-sight distance of approximately 5 miles. The link's terminus at ESD is assumed to be Building 1435, the location of a pilot broadband local area network. The link's terminus for MITRE will be on the MITRE-Bedford complex.

The alternatives considered are:

a. Atmospheric transmissions
   - Microwave
   - Infrared

b. Cable
   - Fiber Optic
   - Coaxial

c. Telephone company lines

d. Private coaxial cable rental

Each alternative can support full duplex, data transmission at a rate greater than 1.5 Mbps and two standard video channels. The performance, cost, and administrative considerations for each alternative are discussed below.

2.1 ATMOSPHERIC TRANSMISSION

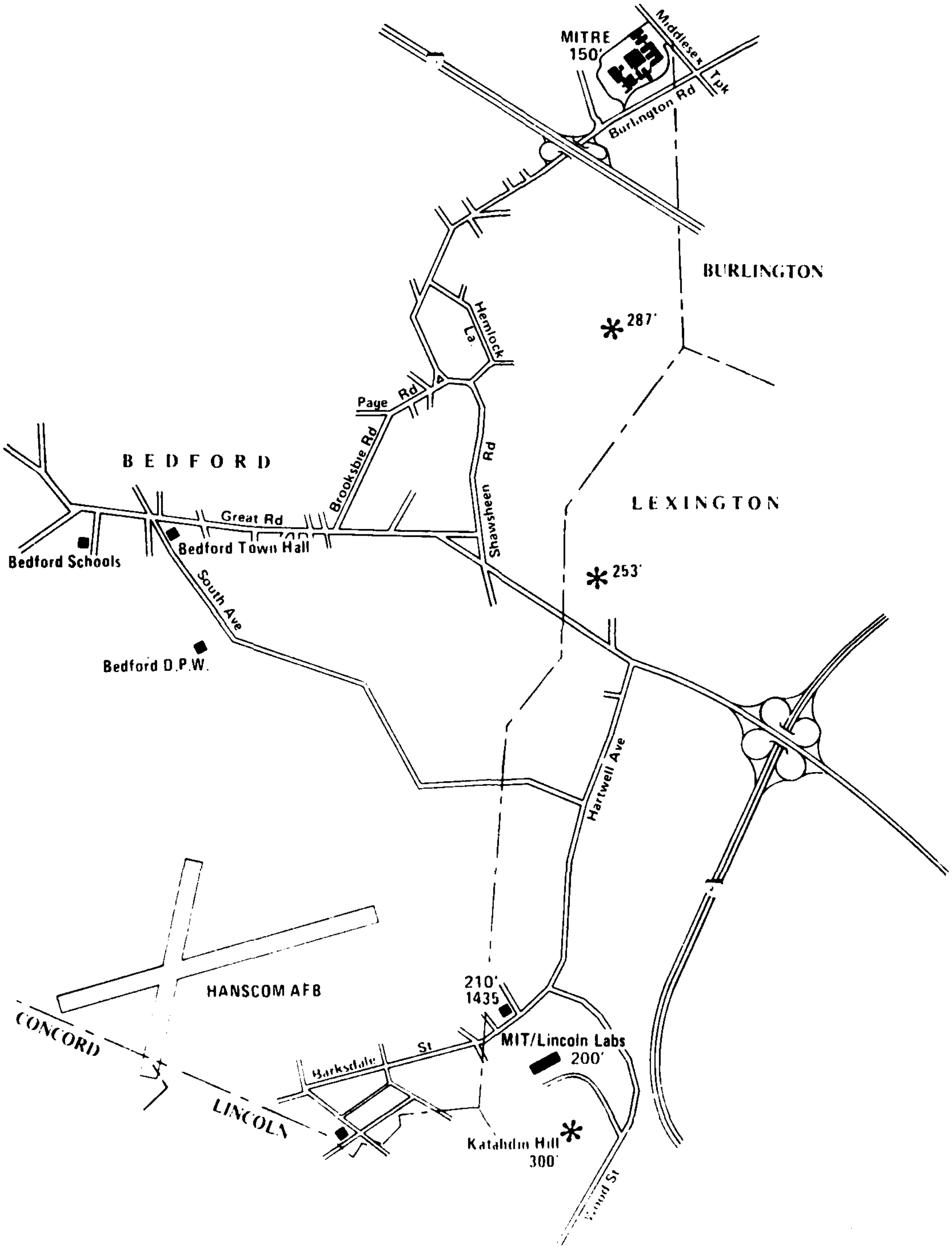
Direct line-of-sight atmospheric transmission betwen MITRE and ESD is hampered by topography and air traffic at the airport adjacent to Hanscom AFB. Hills surrounding the base require that towers be used at the base and MITRE to establish line-of-sight transmission for microwave or infrared links. Intermediate relay or repeater locations are required to avoid topographical obstables and aircraft interference, and to provide suitable performance for the infrared link.

Since Hanscom Airfield is close to the proposed transmission paths (see figure 1), the Federal Aviation Agency (FAA) must approve the transmission plan. FAA form 7460-1, "Notice of Proposed Construction or Alteration," must be filed with the FAA. FEDERAL REGULATIONS PART 77, "Objects Affecting Navigable Airspace," describes FAA requirements.

2.1.1 Microwave Links

Primary considerations for implementing a microwave link between MITRE and ESD are pathway selection, frequency allocation, and equipment specification. Suitable antenna towers for the link at ESD are located at the MIT/Lincoln Laboratory on Katahdin Hill. Two pathways between MITRE and Katahdin Hill are discussed below.

2.1.1.1 Pathways. The topology of the area precludes direct line-of-sight microwave transmission between MITRE and ESD. Therefore, two other pathways are considered.



*Hill with height in feet.

Figure 1. Map of Hanscom AFB, MITRE Bedford and Route I-95.

a. Microwave transmission from MITRE to Boston Hill, Andover, MA and from Boston Hill to Katahdin Hill at the MIT/Lincoln Laboratory Complex, Hanscom AFB, and then cable transmission from Katahdin Hill to the ESD local network in Building 1435 (figure 2). This pathway is prompted by the existence of a MITRE-controlled tower facility at Boston Hill with line-of-sight to MITRE-Bedford. However, tree growth subsequent to last use of the tower could interfere with this path.

b. Microwave transmission from MITRE to a repeater located near Route 128 (I-95) and from the repeater to Katahdin Hill, and then cable transmission from Katahdin Hill to Building 1435 (figure 1). The Baybank Middlesex building at New England Executive Park, Burlington, MA might be a suitable repeater site.

Several administrative activities must be undertaken to insure the validity and accessibility of these pathways. A site survey by qualified personnel is required to assure the technical feasibility of the paths. If pathway "a" is chosen, the lease for the MITRE site at Boston Hill, Andover, MA must be renegotiated. If pathway "b" is chosen, a site for the retransmit station would have to be leased.

The cost of the site survey is estimated to be $2500 - $3500. The MITRE lease on the Boston Hill site expired on December 31, 1981. It is not clear that a new lease could be negotiated with the owners of

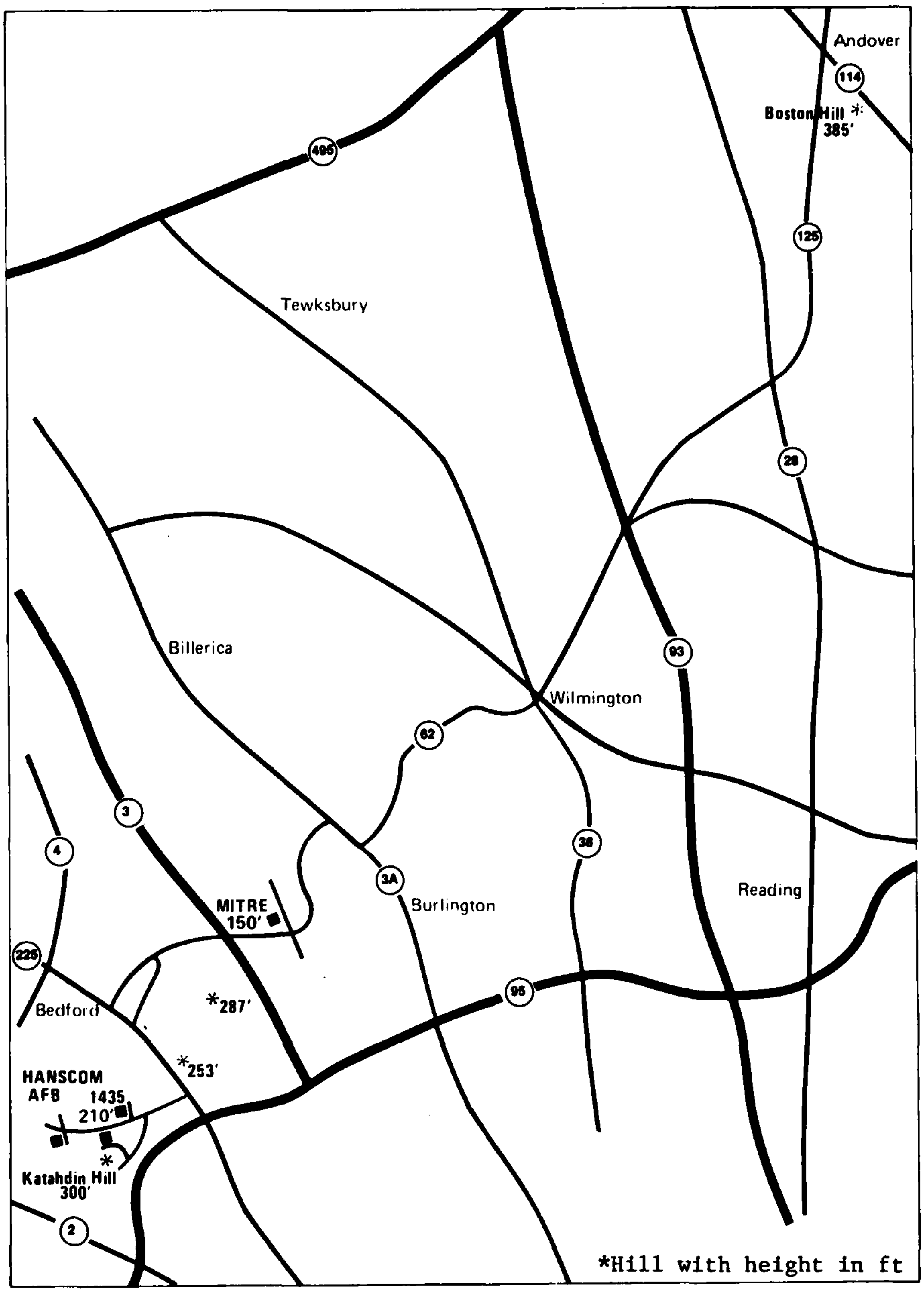


Figure 2. Map of Hanscom AFB, MITRE Bedford and Boston Hill, Andover

the site beyond this date. If this lease cannot be renegotiated, the pathway using Boston Hill would have to be abandoned.

2.1.1.2 Frequency Allocations. Microwave link frequency allocation for this alternative would have to be renewed or granted by the FCC. Typically, 120 days are required to process frequency allocation applications. The broadcast frequencies allocated to MITRE by the FCC for the MITRE to Boston Hill link through 1986 are:

FREQ (MHz)	TRANSMIT SITE	RECEIVE SITE	EXPIRATION	RFA
7355	No And.	Bedford	Jun 83	ESD 81-008
7685	Bedford	No. And.	Dec 86	ESD 81-061
7505	No. And.	Bedford	Dec 86	ESD 81-061
7415	No. And.	Bedford	Dec 86	ESD 81-061

If pathway "b" were selected, it might be possible for the FCC to reallocate frequencies to the proposed Route I-95 repeater point.

ESD/MITRE would have to apply to the FCC for frequency allocations for the Katahdin Hill to Boston Hill link. However, since MITRE has been allocated the unused frequencies listed below, it is very likely that the FCC could reassign these frequencies for paths "a" or "b."

FREQ (MHz)	TRANSMIT SITE	RECEIVE SITE	EXPIRATION	RFA
7385	Westford	No. And.	Dec 86	ESD 81-061
7325	Westford	No. And.	Dec 86	ESD 81-061
7225	No. And.	Westford	Dec 86	ESD 81-061

The FCC has warned that users of frequencies in the commercial bandwidth may have their frequency allocations preempted for satellite communications. Therefore, it is recommended that the ESD/MITRE microwave link be specified to use frequencies in the military bandwidth, precluding the possibility of costly equipment retrofit.

2.1.1.3 Katahdin Hill Considerations. Since Katahdin Hill would be one of the receive/transmit sites for either pathway, administrative arrangements would be required with the MIT/Lincoln Laboratory to use one of their towers. The four towers on Katahdin Hill are described in table 1.

The height of these towers ranges from 50 to 70 feet and the total height, including the Katahdin Hill elevation, ranges from 302 to 332 feet. If the site survey determines that the heights or positions of the towers are not suitable, construction of another tower would be required.

The send/receive station for the Katahdin Hill antennas could be housed in a shelter near the tower. Waveguide from the antennas to the transmitters and receivers is required. A cable from the send/receive shelter to Building 1435 completes the transmission path. Figure 3 shows the geographical relationship between Katahdin Hill and Building 1435. The detailed path for this cable and the shelter position and installation would have to be negotiated with MIT/Lincoln Laboratory.

2.1.1.4 Microwave Equipment. Microwave systems are available that can provide bit error rates (BERs) of less than 10^{-9} with link availability of at least 0.999. For each terminus of each leg of

Table 1

Description of Katahdin Hill Towers

Tower	FPS14	FPS20 Annex 2	FPS6 Annex 2	DABS
Hill Elevation (feet)	257.0	260.5	252.0	256.8
Tower Height (feet)	69.8	71.5	50.0	64.5
Total Height (feet)	326.8	332.0	302.0	321.3
Longitude	71° 15′ 54.60"W	71° 15′ 59.400"W	71° 15′ 59.350"W	71° 16′ 0.99467"W
Latitude	42° 27′ 23.507"N	42° 27′ 22.11"N	42° 27′ 23.359"N	42° 27′ 23.483"N

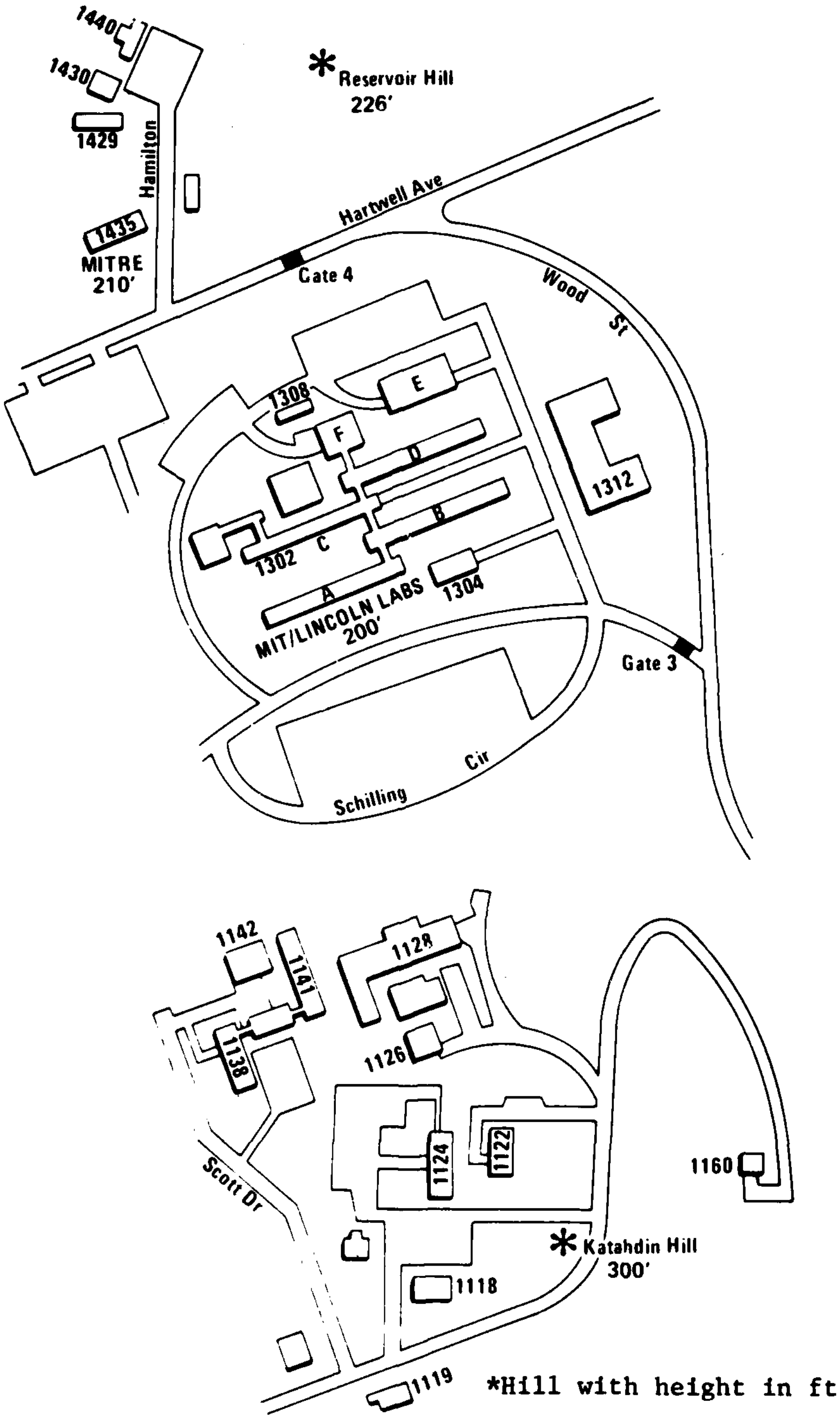


Figure 3. Unscaled Map of Katahdin Hill, MIT/Lincoln Laboratory and Building 1435.

the proposed paths, separate transmitter/receiver pairs are required for the video channel plus accompanying voice, and for the data channel, because the video and data signals at these transmission rates cannot be multiplexed as can lower speed data signals on typical microwave transmitter/receivers without unacceptable signal degradation. The cost estimates provided below are based on the use of separate transmitter/receivers. However, equipment may become available that will support multiplexing of the video and data signals, with attendant reduction in cost.

The price list for components for unprotected (nonredundant) and protected (fully redundant with automatic switching) systems that can support a full-duplex 1.5 Mbps data channel and two-way video transmission with accompanying voice for pathway "a" are shown in table 2a. Costs for unprotected and protected systems are $239.6K and $409K, respectively. The cost of the waveguide and feeder cable from the Katahdin Hill tower to the transmitter/receiver and cabling to Building 1435 will be between $10K and $20K. Thus, the total cost for this alternative for pathway "a" ranges from $250K to $430K, excluding leasing costs.

Costs for unprotected and protected systems for pathway "b" are shown in table 2b. Less expensive, lower-power equipment can be used because pathway "b" is a shorter distance (less than 10 miles) than pathway "a" (the Boston Hill repeater site is over 20 miles from Hanscom AFB or MITRE). However, this less expensive equipment line does not support the hot standby (automatic switching to redundant equipment in case of failure). The costs for unprotected and protected systems are $158K and $230K, respectively. Adding cable costs, the cost for the microwave alternative using path "b" ranges from $168K to $250K, excluding the repeater tower and leasing costs.

Table 2a

Pathway "a" - Hanscom-Boston Hill-MITRE
Microwave Equipment Price List
(M/A Video Systems Company MA-7G Line)
(Reference 1)

Components	Unprotected System Cost	Protected System Cost
Hanscom Site		
2 Transmitter/Receivers	$ 36,400	$ 72,800
1 Audio Channel for TV	4,000	8,000
1 Antenna (including auxiliary hardware)	4,000	4,000
2 Hot Standbys (switch over to duplicate equipment)		4,000
1 Equipment Shelter	10,000	10,000
Installation Estimate-labor (not including feeder cable)		
TV Channel	4,000	4,000
Data Channel	6,000	6,000
Subtotal	$ 64,400	$108,800

Table 2a (Concluded)

Components	Unprotected System Cost	Protected System Cost
MITRE Site		
Replication of Hanscom Site — Subtotal	$ 64,400	$108,800
Boston Hill Site		
4 Transmitter/Receivers	72,800	145,600
2 Antennas	8,000	8,000
4 Hot Standbys (switch over to duplicate equipment)		8,000
1 Equipment Shelter	10,000	10,000
Installation Estimate:		
TV Channel	8,000	8,000
Data Channel	12,000	12,000
Subtotal	$110,800	$191,600
Total	$239,600	$409,200

Table 2b

Pathway "b" - Hanscom-Nearby Repeater Site-MITRE
Microwave Equipment Price List
(M/A Video Systems Company MA 12X Line)
(Reference 2)

Components	Unprotected System Cost	Protected System Cost
Hanscom Site		
2 Transmitter/Receivers	$ 16,000	$ 32,000
1 Audio Channel for TV	4,000	8,000
1 Antenna (including auxiliary hardware)	4,000	4,000
1 Equipment Shelter	10,000	10,000
Installation estimate:		
TV Channel	4,000	4,000
Data Channel	6,000	6,000
Subtotal	$ 44,000	$ 64,000

Note: There is no hot standby equipment available for this less powerful equipment.

Table 2b (Concluded)

Components		Unprotected System Cost	Protected System Cost
MITRE Site			
Replication of Hanscom Site	Subtotal	$ 44,000	$ 64,000
Repeater Site			
4 Transmitter/Receivers		32,000	64,000
2 Antennas		8,000	8,000
1 Equipment Shelter		10,000	10,000
Installation estimate:			
TV Channel		8,000	8,000
Data Channel		12,000	12,000
	Subtotal	$ 70,000	$102,000
Total		$158,000	$230,000

2.1.2 Infrared or Laser Links

Infrared or laser beam transmission could meet the short-haul transmission requirements if the link degradation due to environmental conditions were acceptably low. Infrared transmission is ineffective if the line-of-sight visibility between the transmitter and receiver or repeaters is impaired by weather conditions. Weather data on the ceiling and visibility at Hanscom AFB from 1949 to 1967 in table 3 show the percentage of frequency-of-occurrence of visibility distance, ranging from 0 to 10 miles at ceiling heights ranging from 0 to 300 feet. For example, at an altitude of 300 feet there is a visibility of at least 3 miles 87.9% of the time.

The distance between ESD and MITRE is 5 miles. From table 3, it can be seen that a line-of-sight link without repeaters would be able to operate only 80% of the time because of visibility degradation. To provide reliable data communications comparable to telephone service, a link should have an availability of at least 0.999. Placing repeaters at half-mile intervals would only provide 0.97 availability. With repeaters at quarter-mile intervals, availability would still remain under 0.99.

Lease arrangements for repeaters and safety licenses from the Commonwealth of Massachusetts would have to be obtained to implement this link. Because of the poor performance (low link availability) and above administrative problems, this alternative is not recommended.

Table 3

Ceiling and Visibility at Hanscom Air Force Base
Measured Between 1949 and 1967
all Months and all Hours

Minimum Occurrences of Visibility	Percentage of Frequency of Visibility at Ceilings of:			
Miles	300 Ft	200 Ft	100 Ft	0 Ft
10.00	58.5%	58.5%	58.5%	58.5
6.00	74.8	74.8	74.8	74.8
5.00	79.4	79.4	79.4	79.4
4.00	83.8	83.8	83.8	83.8
3.00	87.9	88.0	88.0	88.0
2.50	89.0	89.0	89.0	89.0
2.00	91.7	91.8	91.8	91.9
1.50	93.2	93.4	93.5	93.5
1.00	95.3	95.8	95.9	95.9
0.75	96.3	96.9	97.0	97.1
0.50	97.0	97.8	98.1	98.2
0.25	97.3	98.2	98.7	98.9
0.00	97.5	98.5	99.2	100.0

2.2 CABLE TRANSMISSION

Coaxial or fiber optic cable links can support full duplex transmission at rates greater than 1.5 Mbps with high performance and reliability. Bit error rates (BERs) of less than 10^{-9} are achievable with a link availability of at least 0.999. Channels supporting many different services ranging from high-speed data to commercial quality video transmission can be provided.

2.2.1 Fiber Optic Cable

Optical fibers are available with bandwidth in excess of 1 GHz-Km. However, connection and signaling considerations require that single fiber strands be used to provide simplex channels between transmitter and receiver pairs. Two transmitter and receiver pairs and two fiber strands are needed for full duplex transmission. For the proposed high-speed digital channel and two-way video transmission, a 4-strand fiber optic cable would be required as a minimum.

Commercial fiber optic transmission equipment is available with a capacity to support a 1.5 Mbps data rate channel, 60 FDM voice or data channels, 24 (TI) or 48 (TIC) pulse code modulation (PCM) channels, or one composite video signal (with audio) over a single optical fiber. Typical link spans using 4dB/km fiber are 4 km for analog FDM, 6 km for digital PCM (T1), and 5 km for analog video.

Although the line-of-sight distance between ESD and MITRE is 5 miles (8 km), the actual distance over existing telephone pole routes could range up to 7 miles (11 km). Therefore, optical repeaters will be required for this alternative.

Unprotected and protected configurations and their costs are shown in table 4. The unprotected configuration is nonredundant and uses a 6-strand fiber optic cable (2 spares). The protected configuration provides total redundancy (including 12-strand cabling) with automatic switching protection. The protected configuration would require a 12-strand cable. Cable cost estimates assume a cost of $.80 per strand/meter. Installation labor costs will be the same as for coaxial cable (see table 5), approximately $90K. Thus, the cost for this alternative ranges from $218K for an unprotected system to $313K for a protected system.

2.2.2 Coaxial Cable

A wide selection of commercial equipment is available to support a 1.5 Mbps data channel and two composite video channels over a coaxial cable link. Unlike fiber optic transmission, many transmitting and receiving devices can share the same cable using FDM techniques. Transmitter and receiver costs for the proposed applications would be nominally $10,000 for a nonredundant and $22,000 for a redundant configuration.

Cable installation cost is $128K for a single coaxial cable link mounted on public utility poles between ESD and MITRE (10 miles). Cost details are shown in table 5. A dual cable installation would cost an additional 30%. Thus, installation of a single cable would cost $128K and a dual cable $166K. The total cost for this alternative could range from $138K to $288K. The utilities charge a yearly fee of $5/pole so that there would be a yearly pole fee of $2,150 (assuming there are 43 poles per mile).

Table 4

Fiber Optic Cable Link Component Costs

Components	Unprotected System Cost	Protected System Cost
Full duplex 1.5 Mbps Channel		
Transmitter/Receiver Pairs (2)	$ 4,400	$ 9,400
Repeater Set	5,500	11,750
Two-Way Composite Video Channel		
Transmitter/Receiver Pairs (2)	4,500	10,500
Repeater Set	5,600	13,100
Fiber Optic Cable (15 km)		
6-strand cable	70,000	
12-strand cable		140,000
Total	$90,000	$184,750

Table 5

Cable Installation Costs for a 10-Mile Single Cable Link Between ESD and MITRE

Item	Cost
Hardware (@ $1/ft.)	$53K
Labor (@ $1/ft.)	53K
Pole Preparation (@ $50/pole)*	22K
Total	$128K

* Pole preparation includes adjusting pole heights and line positions to accommodate placement of the cable. Public utility poles have an allocated horizontal position order and required height from ground for each type of line. There are approximately 43 poles per mile.

2.2.3 Pole Rights and Maintenance

The feasibility of the cable alternatives depends on obtaining pole rights along the route between MITRE and ESD from the town of Bedford and the utility company owning the poles (Boston Edison). The town might be willing to obtain pole rights for the ESD/MITRE cable link if cable could be installed linking some of its town buildings in a local area network. Figure 1 shows that major Bedford town buildings and schools are grouped close to a possible cable route between ESD and MITRE. Provisions would also have to be made for cable maintenance. A maintenance contract with the utilities or cable installation company would have to be negotiated.

2.3 TELEPHONE LINES

The Bell System can provide 1.544 Mbps (T1) digital service (references 3 and 4) that can support data transmission or full motion video teleconferencing using video compression equipment (see section 4.2). No tariff exists for providing this service intrastate. However, MITRE has asked the New England Telephone Company to provide a cost estimate for providing this service between ESD and MITRE.

Cost quotes were obtained for lower speed services. These are shown in table 6. For 19.2 Kbps data transmission, costs are provided for DATAPHONE Digital Service (DDS) and DATAPHONE II Service. These services are described below in more detail.

Table 6

Bell System Costs for Full-Duplex
Data Communications Between ESD and MITRE
at 56 Kbps and 19.2 Kbps

Data Rate	Nonrecurring Charge	Monthly Rate
56 Kbps	384	$ 977
19.2 Kbps (DDS)*	$5,418	$1,468
19.2 Kbps (DII)**	$5,472	$1,333

* Dataphone Digital Service (9.6 Kbps) using duoplexors

** Dataphone II Service (9.6 Kbps) using duoplexors

The Bell System offers data communications services that use dedicated lines and analog and digital transmission facilities. In 1979 the Bell System superseded their analog DATAPHONE Service with DATAPHONE II. This service provides network control and diagnostics for synchronous data transmission using microprocessor-based data sets (modems) over analog, voicegrade, private lines at speeds of 2400, 4800 and 9600 bps. The Bell System also offers wideband analog and digital facilities for transmitting data at speeds of up to 56 Kbps.

DATAPHONE Digital Service is an all-digital network which eliminates conversion of digital data to analog signals (no modems are required). Data Service Units (DSUs) are used to connect devices to the DDS network. Available transmission speeds are 2400, 4800, 9600, 56,000 and 1.544 Mbps (T1 rate). The major DDS advantage is that digital transmission can eliminate the noise and distortion inherent in analog transmission, and thus provide better link performance.

2.4 PRIVATE COAXIAL CABLE RENTAL

Hanscom AFB has already awarded a contract to the Adams-Russell Company to supply entertainment CATV service to the base housing area. The town of Bedford has also awarded a contract for the installation of coaxial cable throughout Bedford to the same company. It may be possible to rent channels from Adams-Russell. However, rental costs in the range of $75 per hour per channel are expected, resulting in a very high annual cost.

SECTION 3

LONG-HAUL ALTERNATIVES

Long-haul, wideband communications can be provided by either the Bell System or satellite carriers. Telenet, TYMNET and other data network services are not considered because they do not support data rates greater than 56 Kbps.

To provide a basis for comparison between the Bell System terrestrial wideband service and satellite carrier services, the wideband communications requirement is assumed to be full duplex, 1.544 Mbps digital data transmission (equivalent to the Bell System T1 service) between the three sites listed below:

a. (ESD) Bedford, MA - (Hq AFSC) Washington, DC
b. (Hq AFSC) Washington, DC - (Space Division) Los Angeles, CA
c. (Space Division) Los Angeles, CA - (ESD) Bedford, MA

Using video compression equipment, a full duplex, 1.544 Mbps data link can support full motion video (described in section 4.2). Satellite carriers prefer to use full motion video for teleconferencing because it is far less expensive and uses less transponder bandwidth than a commercial video signal.

For commercial video customers, satellite carriers transmit the video signal using an FDM-FM (frequency division multiplexing - frequency modulation) format that requires 34 MHz of bandwidth, the full capacity of a satellite transponder. The cost and limited availability of transponders make this approach unrealistic for the proposed application.

3.1 BELL SYSTEM DATA SERVICES

The Bell System 1.544 Mbps Digital Data Service (DDS) was developed to facilitate bulk transmission of digitized data (primarily voice traffic) between private branch exchanges (PBXs) and higher level switching centers. The PBX performs the data concentration (or gateway) functions which multiplex the data from devices locally connected to the PBX onto a 1.544 Mbps DDS trunk line and hence to other switching centers in the telephone network.

The New England Telephone Company installation (nonrecurring) charges and monthly rates for full duplex, data transmission service at 1.544 Mbps, 56 Kbps and 19.2 Kbps between the above sites are shown in table 7. The 19.2 Kbps service is provided by Bell System duoplexors, which support the transmission of data at 19.2 Kbps over two 9.6 Kbps lines. The 1.544 Mbps cost estimate assumes that cable plant exists for providing this service to the buildings where the local networks are located. If not available, additional installation costs will be incurred.

3.2 SATELLITE SYSTEMS

3.2.1 Description*

The organizations that operate the satellites are responsible for the development and continuing operation of their associated

* The description of satellite network operations and limitations is condensed from reference 5.

Table 7

Bell System Costs for Full-Duplex
Data Communications Between ESD, Hq AFSC, and the Space Division
at 1.544 Mbps, 56 Kbps and 19.2 Kbps

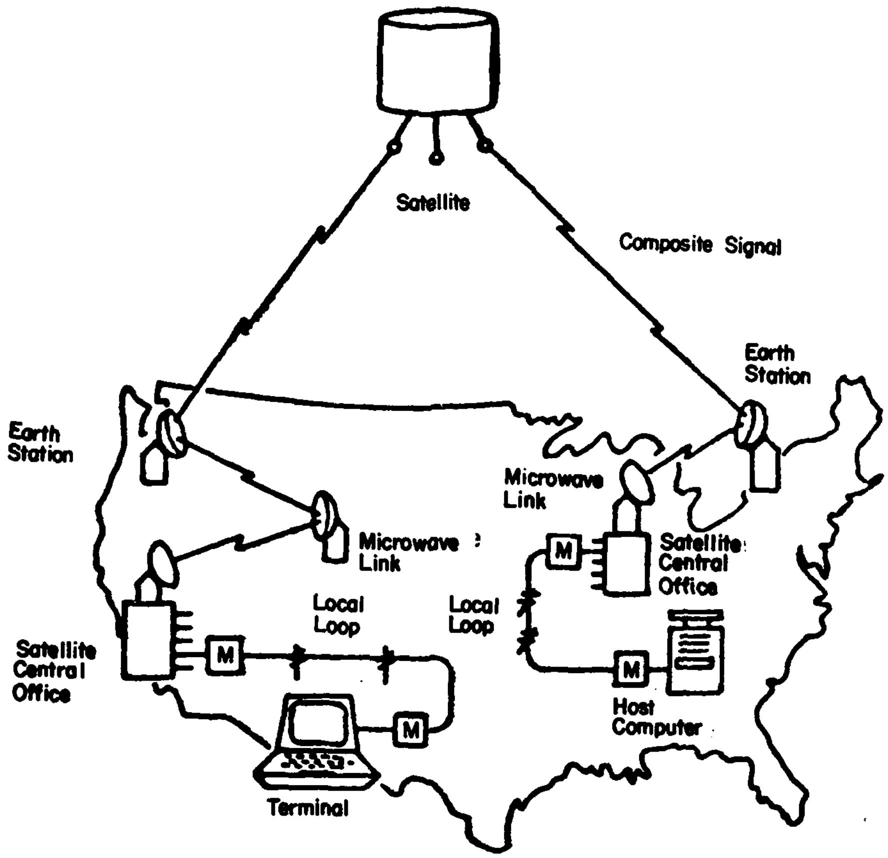
Data Rate	Nonrecurring Charge	Monthly Rate
1.544 Mbps (T1)	$3,000	$270,000
56 Kbps	2,000	28,000
19.2 Kbps (DDS)*	4,700	16,000
19.2 Kbps (DII)**	5,000	18,000

* Dataphone Digital Service (9.6 Kbps) using duoplexors

** Dataphone II Service (9.6 Kbps) using duoplexors satellite systems. They provide common carriers, either wholly owned subsidiaries or independent organizations, with bulk satellite capacity. The common carriers sell satellite communications directly to end-user organizations. The carriers are responsible for the development and implementation of the terrestrial stations and their operation. They are generally not responsible for control of the satellite itself.

Figure 4 shows a simplified satellite communications channel and its components. The channel starts at the gateway to the local area network, which is directly coupled to an on-site earth station via coaxial cable or to the central office of the satellite communications vendor using traditional telephone company facilities. In the latter case, the data is then multiplexed with data received from other sources into a microwave signal that is sent to the satellite vendor's earth station. This composite signal is sent by the earth station to the satellite transponder where it is transmitted to the receiving earth stations using another frequency. At the receiving earth station for a central office facility, the composite signal is broken down into separate channels and distributed using local telephone company facilities. At an earth station dedicated to a local network, the composite signal would be sent to the local area network gateway device for processing and redistribution on the local network.

The distance between a transmitting earth station and any receiving station is essentially the same for all points within the area serviced by the satellite, since the satellite is about 33,000 miles above these stations. Therefore, the ground distance between stations is not a contributing factor to the cost of a satellite circuit. The major costs in establishing a satellite circuit are



M = Modem

Figure 4. Satellite Channel Components

those of the terrestrial stations, the central office facilities, and the satellite itself. The cost of a satellite channel connecting Hanscom AFB to Andrews AFB would be the same as for a channel connecting Hanscom AFB to the Space Division in Los Angeles, CA.

The composite signal between the satellite earth stations and the satellite is assigned to a frequency in the billion-cycle-per-second range (gigahertz). Since the amount of information transferred over a communications channel is directly proportional to the available frequency bandwidth of the channel, satellite channels operating in the high end of the radio frequency spectrum have large transmission bandwidths and can easily accommodate data transfers in the Mbps range.

Satellite channels also provide low error rates. The composite signal is transmitted directly from the terrestrial stations to the satellite and back to the receiving earth station. Although normal terrestrial communications channels use similar microwave circuits for long-haul transmission, these circuits run through the lower atmosphere, more or less parallel to the ground. Therefore, the terrestrial microwave circuits are subject to more atmospheric interference than are the satellite microwave channels. Terrestrial links typically have higher error rates than satellite channels. For example, a satellite channel may achieve a bit error rate in the range of one error in one hundred million bits transmitted ($1x10^{-8}$) while a similar terrestrial transcontinental circuit experiences end-to-end bit error rates of one error in one hundred thousand bits transmitted (1×10^{-5}).

The transponders in the satellite enable each terrestrial station to transmit data at one frequency and receive data at another frequency simultaneously. Thus, a broadcasting earth station can send data to all receiving earth stations, regardless of their location. All receiving stations receive the transmitted signal at the same time.

Because of the high data rates in the composite signal between the terrestrial stations and the satellites, cost-effective use requires that data from many sources be combined and transmitted in the composite signal.

3.2.2 Limitations

Although satellites offer the advantages of insensitivity to distance, point-to-multipoint communication capability and improved transmission quality over long distances, there are some limiting characteristics to satellite communications. Some of these are discussed below.

3.2.2.1 Point-to-Point. Although satellite communications could be directly broadcast to all users, an earth station would be required at every user site, which would be prohibitively expensive. Therefore, satellite communications is used to provide point-to-point channels useful primarily as backbone circuits carrying a heavy data communications load and as overall data communications networks. However, satellite vendors are developing new techniques for connecting local sites to satellite systems to form overall digital communications networks. Techniques for economically distributing communications service to user sites should also reduce the negative effects of point-to-point satellite channels.

3.2.2.2 Resolving Transmission Delay. In data communication networks, transmission delay is a determining factor in overall system performance and system response time. The long signal propagation delay over a satellite circuit increases response times and lowers system performance in networks using block-by-block acknowledgment error control. Error control protocols, such as IBM's Binary Synchronous Communications (BSC) protocol, require that the transmitting station receive an acknowledgment from the receiving station before transmitting another block of data. When satellite circuits are used, the transmission delay between blocks can easily be as much as half a second. Because satellite channels have a low error rate, a simple means of reducing the delay is to increase the size of the blocks transmitted over the satellite communication channel. This approach can significantly increase the throughput of the channel.

A more effective means of significantly increasing throughput while decreasing response time over satellite channels is to use a Go-Back-N-Repeat request protocol. In this type of protocol, the sending station transmits blocks of data in sequence without awaiting an acknowledgement for each block from the receiving station. If the receiving station detects a block with an error, it requests the sending station to retransmit that block only. IBM's Synchronous Data Link Control (SDLC) is similar to the Go-Back-N-Repeat request protocol, but is less sophisticated because the sending station must transmit both the block in error and all the following unacknowledged blocks. Both these techniques provide superior satellite channel performance compared to block-by-block acknowledgement protocols.

The techniques described here for overcoming the transmission delay on satellite channels are available and will be offered by satellite common carriers as special equipment attached to the end of each satellite channel. American Satellite Corporation provides a satellite delay compensation unit (SDCU) that incorporates an advanced delay-insensitive communications protocol for transmission over the satellite channel to eliminate the negative effects of propagation delay. Similar units will be provided in the networking services proposed by SBS.

3.2.2.3 Overcoming Rain Attenuation. Only a limited number of communication satellites are in synchronous earth orbit covering specific geographic areas within a pair of radio frequencies. Simultaneous transmissions at the same frequency in the same place interfere with each other. Sufficient spacing between satellites must be provided to ensure a low level of radio interference from earth stations and adjacent satellites. There are only about six prime slots for coverage of the North American continent within each set of radio frequency assignments. Current frequency assignments are the 4/6, 12/14, 20/30 and 30/40 gHz bands; current satellite systems use the 4/6 gHz and 12/14 gHz bands.

In the higher frequency bands, rain can absorb nearly all the signal power in transmission from the satellite to the ground stations. This down-link signal power is limited because it is derived from solar panels with fixed power production. In the up link more power is available in the ground stations, and a loss of signal power due to rain can be overcome by supplying increased power to the transmission. Rain attenuation of the signal is significant only when there are heavy thundershowers; fortunately such thundershowers usually cover only a small area of about one mile in diameter.

3.2.3 Satellite Carrier Service

Each satellite carrier's services and earth station/video teleconferencing equipment lease arrangements and general cost considerations are discussed below. Since Satellite Business Systems (SBS) is considered the prototype of a new class of long-haul telecommunications carriers for corporations and government agencies that want dedicated networks that provide premiere service, it is described first.

3.2.3.1 Satellite Business Systems. The SBS (reference 6) networking scheme is shown in figure 5. This scheme is designed to provide an integrated, all-digital private communications network for organizations with large communications requirements. SBS customer-premises earth stations (CPESs) reflect the SBS system-design requirements for relatively small size, high reliability, ease of maintenance, and low-cost, unattended operation.

The principal components of a CPES are the radio frequency terminal, the burst modem, the satellite communications controller, the port adapter system, and the monitor and command loop.

Separate and remote from individual CPESs, there is a large-scale data-processing and control facility, called the Network Control Center, located near SBS headquarters in McLean, Virginia. The Network Control Center enables SBS to monitor the operation of every CPES and, if conditions warrant, to effect certain operational changes.

The radio-frequency terminal (RFT), which can be placed on a rooftop, a parking lot or similar site, is the transmitter and

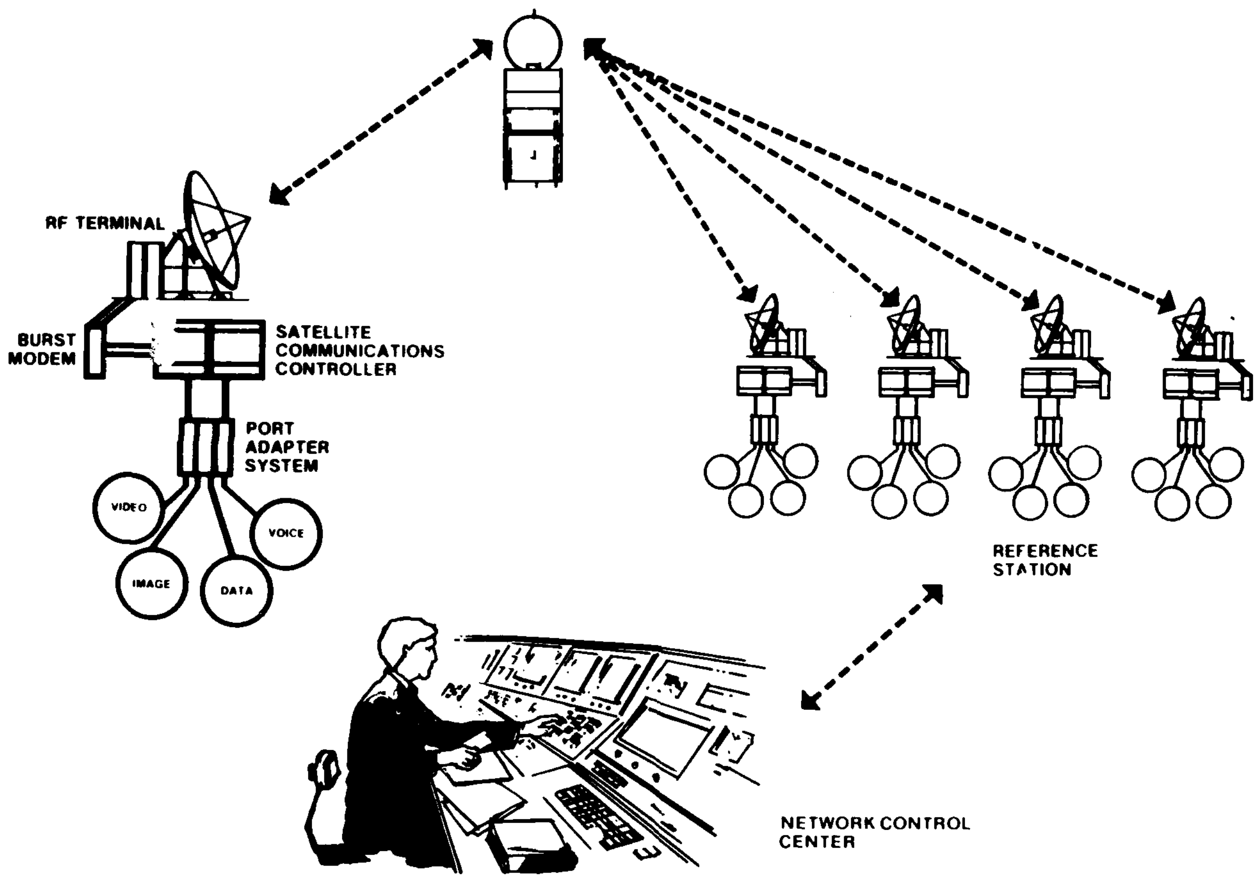


Figure 5. SBS Networking Scheme

receiver of radio signals to and from the SBS satellite. It has several components, including a parabolic antenna, signal converters, power amplifiers, a low-noise receiver, and an equipment shelter. The nominal diameter of the antenna is either 5.5. or 7.7 meters, depending on the site location.

The remaining CPES equipment is housed inside customer facilities adjoining the RFT, with connection to the RFT provided via a wideband communications cable.

Within the earth station, signals to and from the RFT are processed by the burst modem (modulation-demodulator), which sends outgoing traffic in precisely measured bursts to the RFT and regenerates incoming traffic bursts for processing by the satellite communications controller (SCC).

The SCC is a computerized communications processor that performs traffic switching, time-division multiplexing, multiple-access control, demand-assignment control, echo suppression, and analog/digital conversion of voice signals.

Another SCC function is active at only one of the many earth stations that can share an SBS satellite transponder. (There are 10 transponders in an SBS satellite). This function is to serve as the reference station for that transponder in the synchronization of time-division multiple access. The SCC at a reference station monitors the traffic bursts among the other earth stations and assigns to each burst its own protected time slot. Every CPES, through the SCC, has the capability to service as a reference station.

Connection between the earth station and the customer's local terminal equipment (e.g., PBXs, computers, electronic mail system, video teleconferencing equipment, etc.) is provided through the port adapter system (PAS). At each CPES location the PAS is a set of industry-standard interfaces that can accommodate a wide range of customer-supplied equipment. It is, in effect, the input-output device for the satellite communications controller.

The status of all earth-station components is sensed continuously via the monitor and command (M&C) loop. By means of the M&C loop, the Network Control Center can receive status and diagnostic information and can command operational changes. The Network Control Center also provides billing and traffic information and furnishes a variety of other administrative support functions.

SBS began operation in January, 1981, offering service such as telephone communications; computer-to-computer links; high-speed, electronic document communications; and video teleconferencing. SBS requires a company or government agency adopting the service to have at least three earth stations on its premises. These "network access centers" are owned and maintained by SBS. The basic monthly charge for each center is $12,500.

SBS assigns satellite-transmission capacity in blocks called "transmission units." One unit is equivalent to 224 Kbps of simplex capacity. There are two types of units: the full time transmission unit and the demand transmission unit. A full-time transmission unit is 224 Kbps assigned to a network 24 hours a day, 7 days a week. A minimum number of these units equal to the number of network-access centers is required for a user network. The monthly charge per full-time transmission unit is $2,100. The "demand transmission unit" is assigned to a network on a demand or contention basis from a pool of satellite capacity. This transmission unit is available to accommodate occasional or unexpected peaks in customer usage. The charge for this unit is approximately $40 an hour.

The final component of the network, which has its own set of charges, consists of "connection-arrangement units (CAUs)." These units provide the connection between customer equipment, including PBXs and computers, and the satellite network-access center. Analog and digital connections are provided on a switched or nonswitched basis. Nonswitched connections require dedicated transmission capacity and a dedicated CAU at each network access center on the connection. Switched connections are established as needed by the call originator. There are three kinds of CAUs: analog, with monthly cost from $50 to $110 each, depending on the number of connection arrangements per network-access center; digital for nonswitched service, with monthly costs from $150 to $3,000 each, depending on the data rate; and digital for switched service, with monthly costs from $165 to $3,000 each, depending on the data rate.

The total charge for what SBS calls Communications Network Service-A (CNS-A) depends on a customer's specific configuration. This charge would be the sum of the rental fees for at least three earth stations plus the cost of transmission units. An organization's typical total monthly costs for voice, video and data applications, such as electronic mail, would be:

- Three network-access centers (at $12,500 each) = $37,500.
- Twenty-five full-time transmission units (at $2,100 each) = $52,500.

o Four switched digital 1.5-Mbps connection-arrangement units (at $2,750 each) = $11,000.

o Total per month = $101,000.

Large SBS customers will probably find their monthly bills to be even higher than shown above. SBS promises in its FCC filing that, at a customer's request, SBS will contract with other common carriers or construct the necessary facilities to link the customer's network-access centers with the rest of the customer's locations, including remote sites.

The company's second private-network offering, Communications Network Service-B (CNS-B), will offer many features of CNS-A. Each CNS-B network will have a minimum of three network-access centers, but one of these may be a "service point," which is an SBS facility not situated on the user's premises. Initially limited to voice applications, these service points eventually will accommodate digital data communications up to 56 Kbps. SBS's planned rates for this service are $7,500 per month for each network-access center and $3,000 per month for each service point. Full-time transmission units will cost $2,100 each.

The company also has asked the FCC for authorization to permit CNS-B customers to place voice calls from locations on their networks to off-network sites via shared telephone company facilities between CNS-B earth stations and telephone company exchanges. This option became available with CNS-B in January, 1982. CNS-B users initially will be able to access off-network stations in 75 U.S. metropolitan areas and in 150 areas by mid-1983. The tariffs for this optional feature are 15 cents per minute from an earth station or SBS facility for the initial 120 hours during a monthly billing period, 10 cents per minute for the next 480 hours, and 9.5 cents per minute beyond 600 hours.

SBS plans to establish a network of 20 earth stations and associated facilities to provide a low-cost interstate voice service connecting 150 U.S. cities. The company will offer a WATS-like service, based on dedicated access channels between a customer's calling locations and the SBS earth stations. It will also provide dial-up access to the earth station using identification codes.

3.2.3.2 American Satellite Company. American Satellite Company (ASC) provides private line and specialized network services to commercial and government customers throughout the U.S. ASC has provided various services to government users such as transmission of data critical to space exploration, weather maps, flight test data for the F-16 fighter, encrypted voice conversation, and wideband computer data from ship and land-based locations.

The services ASC provides fall into four major categories: General, Government Dedicated, Satellite Data Exchange (SDX), and Network Services. Most ASC customers subscribe to private-line voice and data circuit service provided by General Service facilities. These circuits can be used 24 hours a day for telephone conversations or transmittal of data at speeds up to 9.6 Kbps.

Services to government customers characteristically consist of wideband data channels that link their facilities through networks of on-location earth stations. The SDX Service uses a single satellite link to simultaneously transmit and receive one or more types of communications (digital data, telex, digital voice, telegram, facsimile, electronic mail and business video) between two or more locations. Network Services include managing a customer's global communications network, operating a group-user voice channel concentrator service between metropolitan areas, and designing value-added services.

ASC's wide bandwidth SDX Service (reference 5) is provided through specialized ASC networks with earth stations located in major population centers across the U.S. Currently operating at all-digital data rates up to 1.544 Mbps, specialized networks can provide:

- High-speed data service through multiple channels at rates of 1.544 Mbps, with 10-meter-diameter antenna earth stations on customer premises or nearby rooftops.

- Medium-speed data service through multiple channels at rates of 56 Kbps, with 5-meter-diameter antenna earth stations on customer premises or nearby rooftops.

Equipment at specialized network earth stations consist typically of a 5-, 7- or 10-meter-diameter antenna, a weatherproof electronics shelter that measures 6 by 8 by 8 feet and transmit/receive equipment. This will provide one or more communications channels operating at minimum data speeds of 56 Kbps. Full- and half-duplex unattended operation and simultaneous transmission in a broadcast mode or specific transmission to individual customer stations can be provided. A minimum service period of 36 months applies to specialized network offerings. A 60-month contract is optionally available.

ASC's rates for satellite transponder time, if available, is $2,500 per month for 56 Kbps increments. A 1.544 Mbps channel costs $12,000 per month. This service may be purchased at an hourly rate of $250 for the first half hour and $150 for each additional hour.

The rental fee is $5,000 per month for two 5-meter-diameter antenna earth stations that would support 56 Kbps data rate transmission between two sites. The monthly rental costs for video teleconferencing at the 1.544 Mbps full motion rate for a three-way configuration are:

- Three 10-meter-diameter antenna earth stations (at $12,000 each) = $36,000.
- Three portable video equipment roll-in carts (at $1,800 each) = $5,400.
- Three 1.544 Mbps transponder channels (at $12,000 each) = $36,000.
- Total per month = $77,400.

3.2.3.3 <u>RCA American Communications Incorporated</u>. RCA American Communications Incorporated (RCA Americom) provides private line and specialized network services to commercial and government customers throughout the U.S. that are similar to ASC's services. Private-line channels are offered for long-distance communications between designated metropolitan areas that are served by satellite earth stations and their terrestrial microwave extensions.

RCA Americom has installed earth station facilities at Sunnyvale Air Force Station, California, to provide a high speed (6.144 Mbps) service between this site and Thule Air Base, Greenland. It also provides a high speed data link between the Sunnyvale Facility and NASA's Goddard Space Flight Center in Greenbelt, Maryland. This service consists of a 224 Kbps data channel from Goddard to Sunnyvale and a 56 Kbps data channel from Sunnyvale to Goddard. RCA Americom provides two-way service between Sunnyvale and Cape Canaveral as well. This service is a 768 Kbps data channel from

Cape Canaveral to Sunnyvale and a 192 Kbps data channel from Sunnyvale to Cape Canaveral. The Sunnyvale and Goddard earth station sites are near the Los Angeles and Washington, DC local network sites, respectively, and could provide earth station support to these local networks via local common carrier lines at the 56 Kbps data rate.

RCA Americom's rate for transponder time, if available, is $1,500 per month for a 56 Kbps channel. A 1.544 Mbps channel costs $10,000 per month. The rental fee for a 5-meter-diameter earth station suitable for 56 Kbps Plus Service is $1,500 per month. The monthly rental fee for a 10-meter-diameter antenna earth station to support video teleconferencing is $12,000 per month. Costs for a three-way configuration to support full-motion video teleconferencing at 1.544 Mbps per channel are:

- Three 10-meter-diameter antenna earth stations (at $12,000 each) = $36,000.
- Three 1.544 Mbps transponder channels (at $10,000 each) = $30,000.
- Video teleconferencing facility (not provided by RCA Americom).
- Total cost per month without studio facilities = $66,000.

3.2.3.4 Western Union Satellite Transmission Service. Western Union's (WU's) Satellite Transmission Service (reference 5) provides interstate data, voice, teleprinter, and wideband transmission facilities. Westar I, II, and III make up the WU satellite family.

Interconnection with customer-provided land-based facilities or with facilities provided by another common carrier or an international carrier is permitted. Access to either customer-provided earth stations or to WU-provided earth stations is also a part of the system service. The communications satellites are capable of handling:

- o Private line voice traffic
- o Alternate data/voice traffic
- o Two-way, point-to-point data traffic
- o Full-time video channels
- o Occasional video channels

WU owns earth stations which provide service to major U.S. population centers. Microwave radio links connect each earth station to WU's existing 8000-mile, cross-country microwave transmission system and through that system to WU's local transmission facilities on a nationwide basis.

For the operation of its Satellite Transmission Service to meet the requirements of an individual customer, Western Union can provide any combination of:

- o Earth stations
- o Extension channels
- o Satellite channels
- o Terminal equipment
- o Terrestrial facilities

An individual customer may also elect to furnish any part or parts of the system for use with WU provided satellites.

Two types of access to WU satellite transponders are offered. One type of access is through one of the WU earth stations; the other is through customer-owned earth stations. WU can furnish a full transponder dedicated to an individual customer's use on a single- or multiple-access basis, or it can furnish individual channels.

Satellite Transmission Service provides analog channels for point-to-point or for point-to-multipoint operation and digital channels for point-to-point operation. Service is offered 24 hours a day, seven days a week and can be provided on a protected or unprotected basis.

Protected service allows replacement transponders to be designated and reserved by WU. The replacement transponders will be provided on the basis that all transponders used by a particular customer will be in the same satellite unless the customer requests otherwise. Unprotected service does not allow for such designated replacement transponders.

The following channel arrangements are available:

- Month-to-month transponder service
- Fixed-term transponder service, including protected and unprotected
- Voice grade channel service providing a nominal 4 KHz bandwidth channel for voice transmission and a 9600 bps channel for data use, or for both voice and data on an alternate use basis.
- Wideband channel service at 40.8 Kbps or 50 Kbps.

- Experimental channel service
- Multiple-access special channel service
- Specific period transponder service
- Video channel services, including
  - long-term commitment, and
  - occasional use service

Since Washington, DC and Los Angeles are among the WU access cities, it may be possible to provide the wideband services required to the Air Force sites using WU earth station facilities and local communications links.

WU does not lease earth stations or studio equipment for teleconferencing. WU will provide full transponder video teleconferencing, but not 1.544 Mbps full motion video. No cost information for this service was provided.

3.2.3.5 Bell System (AT&T) Satellite Service. AT&T has filed a tariff with the Federal Communications Commission (FCC) to provide two-way video teleconferencing by the end of 1982 in 16 U.S. cities. Washington and New York, the first cities in the network, started service that year. By 1984, the ''Picturephone Meeting Service'' should be expanded to include 42 cities.

Customers can link their own video conferencing facilities to the full color, digital terrestrial/satellite network or rent AT&T rooms equipped with cameras, graphic devices, hard copy machines and video tape recorders. A one-hour meeting between public rooms in New York and Washington, DC, will cost $1,340. The same meeting between private rooms will cost $600. Any room will be able to communicate with any other room on the network. AT&T will outfit private rooms at $124,800 for installation plus monthly fees of $13,420 for equipment rental and $250 per mile between the room and AT&T's facilities.

3.2.4 Earth Station Configurations

Government ownership of the satellite earth stations may be a desirable alternative to the earth station leasing arrangements of the satellite carriers. Two earth station configurations are described that can provide wide bandwidth data or video communications. The component lists and price quotations for these configurations provided by Scientific Atlanta are contained in appendix A.

3.2.4.1 Five-Meter Antenna Redundant Transmit/Receive Digital Earth Station. This system provides from one to eight 56 Kbps channels and redundancy throughout for reliable service. Each 56 Kbps channel can carry a 56 Kbps data circuit or can be multiplexed to carry multiple, lower speed data circuits. Voice channels can be derived using CVSD modulation. To support data transmission rates over 1 Mbps, Scientific Atlanta recommends using their model 8813 duplex QPSK modem/codec. Using a video compressor to produce a 1.5 Mbps signal and the 8813 QPSK modem/codec, video teleconferencing could be supported as well by this configuration.

3.2.4.2 Ten-Meter Antenna Redundant Transmit/Receive Earth Station. This earth station was designed to provide high quality video reception and transmission. It provides two 24-channel video receivers with both 6.2 MHz and 6.8 MHz audio subcarrier demodulations (the audio is transmitted separately from the video) and automatic switching, and two 2.8 kw high power amplifiers (HPA) with automatic protection switching, hybrid combiner and loads to allow occasional transmission of two simultaneous uplinks. The transmit/receive station with full transponder video transmission costs $375,000. The cost to support 1.544 Mbps data transmission as well as video is $603,000.

SECTION 4

NETWORK INTERCONNECTION CONSIDERATIONS

The TV and data channels on the local networks must be connected to whatever media is chosen for the short- and long-haul wideband links. These connections (gateways or interfaces) will vary according to the media or carrier chosen. A complete technical description of the interfaces is beyond the scope of this document. However, the following discussion highlights some of the gateway functions and gateway/media interaction for interconnecting these networks that may influence:

a. Media selection,
b. Interface design,
c. The use of the 1.5 Mbps data transmission capacity, and
d. Adherence to the full-motion video requirement.

4.1 WIDEBAND DIGITAL DATA GATEWAYS

With the exception of the short-haul broadband coaxial cable alternative discussed in section 2.2.2 where the ESD and MITRE networks might be directly connected, the wideband digital data gateways to interconnect local networks to short- or long-haul wideband data links are not commercially available and will require development effort. A gateway device will be similar to the bus interface unit (BIU) of the local network to which it is connected. Most BIUs provide an RS-232-C, X.25 or other interface compatible with a user device such as a terminal or computer.

A similar interface must be provided to the modem (or transmit/receive device) used to communicate over the wideband data link. In addition, this interface must support network layer protocols to assure reliable data transmission between devices on the interconnected local networks. Protocol functions include link initialization, packet addressing and framing, link management and flow control, error control, transparency of message characters to link control functions and abnormal condition recovery. A complete discussion of these protocol considerations is contained in references 8, 9, 10 and 11.

In addition to the cost of the gateway device, additional costs may also be incurred for multiplexing several lower speed data channels with the 1.5 Mbps channel. For example, a 20-channel multiplexer suitable for multiplexing 64 Kbps channels onto a T1 link costs approximately $40K. Since a multiplexer would be required at each end of the data link, this would add $80K to the cost of any of the proposed wideband data link options.

4.2 TWO-WAY VIDEO TRANSMISSION

Although several of the short- and long-haul alternatives can support two-way video transmission using channels that transmit the composite video signals within the nominal 6 MHz bandwidth used for commercial television, some alternatives can provide only full-motion video (i.e., video digitized and compressed to a 1.5 Mbps transmission rate) which requires digitization and compression of the video signals so they can be transmitted using less bandwidth at the T1 rate of 1.544 Mbps. This is accomplished using video compression equipment which costs $100K per site. Compression equipment can also be used to transmit freeze frame or slow scan video at rates ranging from 56 Kbps to 224 Kbps if lower cost transmission rates are desirable. For teleconferencing in which participants exhibit limited movement, the picture quality of full-motion video is almost indistinguishable from composite video. Freeze frame or slow scan video transmission (reference 10) is possible at lower rates (128 Kbps or less), but is used primarily for transmitting pictures of static objects such as diagrams, charts or vugraphs.

Video compression consists of a color (or monochrome) freeze video picture transmitter and receiver employing digital pulse code modulation techniques, along with band compression for use on frequency bandwidths ranging from 1.544 Mbps to as low as 2.4 Kbps. Using video compression, the flicker rate remains the same as for composite video. However, a new picture frame is shown only two times in a second. Movement appears disjointed at this rate only if video teleconference participants rapidly change their position.

The Nippon Electric Company (NEC) video compression equipment, NETEC-X2 CODEC, can be purchased for approximately $100K. This CODEC provides a 40-fold reduction in transmitted bandwidth for a full-motion color television video signal. It operates on the principle of interframe encoding, whereby the same picture element in successive picture frames is examined and only the difference or change in scene is transmitted. This technique permits a vast reduction in transmitted information since much of a television picture does not change from frame-to-frame (reference 11).

The compression/decompression equipment provides good quality full-motion video (i.e, video digitized and compressed to 1.5 Mbps) TV coverage with proper voice synchronization. The video compression equipment provides a signal compatible with the composite video format that can be transmitted on the local network directly or through a frequency converter.

4.3 SECURITY

Short- and long-haul communications are vulnerable to electronic eavesdropping unless encryption is used. If secure communications are required, it would most likely affect the gateway design. Therefore, security requirements should be identified so that they can be addressed during gateway development.

SECTION 5

SUMMARY

The wideband gateway alternatives discussed previously are summarized below.

5.1 SHORT-HAUL ALTERNATIVES

The six short-haul alternatives listed below support full duplex, data transmission at a rate greater than 1.5 Mbps and two standard television channels.

a. Microwave
b. Infrared beam
c. Fiber optic cable
d. Coaxial cable
e. Bell System T1 (1.544 Mbps) service
f. CATV cable channels (leased from a private company).

A synopsis of the performance, cost, and administrative requirements associated with each alternative is given below.

5.1.1 Microwave

The microwave alternative can be implemented using repeaters on Boston Hill (pathway "a") or a tower near Route I-95 midway between ESD and MITRE (pathway "b"). Either pathway could provide excellent performance: a BER of less than 10^{-9} and availability greater than

0.999. The cost for pathway "a" ranges from $250K to $430K, and for pathway "b" from $168K to $250K (excluding the cost of a repeater tower). Administratively, ESD/MITRE will have to negotiate a lease for a site at either Boston Hill or near Route I-95. ESD/MITRE will have to petition the FCC for repeater frequency allocations.

5.1.2 Infrared Beams

The infrared beam alternative could not provide an availability better than 0.99. Therefore, its implementation is not recommended.

5.1.3 Fiber Optic Cable

The fiber optic cable alternative could provide excellent performance: a BER of less than 10^{-9} and availability greater than 0.999. Costs for the fiber optic alternative range from $218K to $313K. ESD/MITRE would have to petition the town of Bedford for use of the utility poles. Agreements between Bedford and the utility companies would be required to implement this alternative.

5.1.4 Coaxial Cable

The cable alternative could provide excellent performance: a BER of less than 10^{-9} and availability greater than 0.999. The cost of this alternative ranges from $138K to $288K. The administrative problems would be the same as for the fiber optic cable alternative.

5.1.5 Bell System Tl Service

Bell System Tl service is not available between ESD and MITRE. The New England Telephone Company has agreed to provide MITRE with an estimated cost for this service. If the ESD/MITRE data transmission requirements were 56 Kbps or less, the telephone company could provide 56 Kbps and 19.2 Kbps services as shown in table 6. The most cost-effective service is 56 Kbps with a non-recurring charge of $400 and a monthly rate of $1,000.

5.1.6 CATV Cable Channels

Adams-Russell, the CATV franchisee for the town of Bedford, has not yet set rates for leasing channels on their network. If this network were interconnected with the Hanscom AFB cable network to be installed by the Adams-Russell Company, the proposed applications could be supported by these networks.

5.2 LONG-HAUL ALTERNATIVES

Bell System terrestrial and satellite carrier services were investigated in section 3 that could support wideband transmission of digital and video information between local networks separated by distances over 100 miles. The local network sites were selected to provide examples of mid-range and long-range interconnections.

The satellite carriers examined that could provide the desired wideband services were:

a. Satellite Business Systems (SBS)
b. American Satellite Company (ASC)
c. RCA American Communications Incorporated (RCA Americom)
d. Western Union Satellite Transmission Service (WU)
e. Bell System Satellite Service.

No recommendation was made as to which satellite carrier offered the best service because selection of a satellite carrier will depend on the user application, availability of satellite transponder capacity, the accessibility of a satellite carrier's earth station facilities to the user's sites, and whether the user wishes to lease or buy earth station and teleconferencing studio equipment. However, it was possible to compare Bell System terrestial and satellite carrier services for providing three full-duplex, 1.5 Mbps data links between the local network sites. Wideband satellite communications service is half as expensive, provides better performance (BER of 10^{-8} vs. 10^{-5}) and greater channel capacity (full transponder bandwidth is 40 Mhz) than the Bell System terrestrial service. Monthly rates for three full-duplex, 1.5 Mbps data links between the Air Force sites over Bell System terrestrial links would be $270K (from table 7). Table 8 shows that monthly satellite carrier fees for a similar service range from $100K to $150K. Government ownership of the earth stations could reduce these monthly charges by $40K to $60K. However, the estimated cost for each earth station is $373K (see appendix B).

Table 8

Satellite Carrier
Monthly Costs For Three Full-Duplex
1.544 Mbps Channels

Cost Item	Satellite Carrier		
	SBS	ASC	RCA Americom
Transponder Tranmission Units	$88K	$72K	$60K
Earth Station Rental	$40-60K	$40-60K	$40-60K
TOTAL	$128K-148K	$112K-131K	$100K-120K

5.3 CONCLUSIONS AND RECOMMENDATIONS

5.3.1 Short-Haul Alternatives. The Bell System T1 service and CATV cable channel alternatives cannot be evaluated without further information. The remaining alternatives were evaluated as follows:

a. Infrared Beam - Poor visibility and low cloud ceiling occur all too frequently to permit reliable communications over the 5-mile distance between Hanscom AFB and the MITRE complex. Accordingly, this media is not recommended for the ESD/MITRE wideband gateway.

b. Fiber Optic Cable - Although this is a technically viable alternative, it is more expensive to implement than coaxial cable and requires separate fiber optic strands for each optical transmitter/receiver pair, limiting the number of channels that can be supported. Thus, this alternative is not recommended for the ESD/MITRE wideband gateway.

c. Coaxial Cable - This alternative can provide the most usable bandwidth (400 MHz) with excellent performance and would be less expensive to implement than a fiber optic wideband gateway. Administratively, it would require negotiation of utility pole rights. This alternative is recommended as a candidate for the ESD/MITRE wideband gateway.

d. Microwave - Both the pathway "a" and "b" microwave alternatives can provide the desired connectivity with excellent performance. These options will require negotiation of a lease for a site at Boston Hill or near Route I-95. The microwave alternatives are also recommended as candidates for the wideband gateway.

In terms of known costs, the technically viable alternatives rank as follows:

a.	Coaxial Cable:	\$138K to \$288K
b.	Microwave (pathway "b")	\$168K to \$250K
c.	Fiber Optic Cable	\$218K to \$313K
d.	Microwave (pathway "a")	\$250K to \$430K

Thus the coaxial cable alternative costs the least and provides the greatest capacity. However, the deciding factor will probably be which alternative's administrative problems can be surmounted more readily.

It is difficult to estimate time periods required to install the above alternatives, because all of these alternatives involve administrative negogiations with non ESD/MITRE parties for leases, pole rights, etc. However, a reasonable estimate would be between 12 and 24 months.

The above recommendations are based on site specific factors listed below that could vary depending on the sites of interest:

a. Topography,
b. Weather and other environmental factors,

c. Locations for antennas, tranmsitters and receivers,
d. Government regulations,
e. Availability of public utilities and common carriers, and
f. Utility pole rights.

For a different pair of sites, a similar analysis would be required to determine the most suitable short-haul alternative.

5.3.2 Long-Haul Alternatives

A wideband satellite communications network is the preferred alternative because it would be half as expensive as Bell System terrestrial service, and provide better performance and greater channel capacity. Two options exist for establishing this network:

a. Lease the service from a satellite carrier.
b. Procure the satellite earth stations and rent transponder time.

The monthly leasing costs for the three-site configuration proposed in this report are shown in table 8 and range between $100K and $150K. These costs include the rental fees for the three earth stations and transponder time for three, full-duplex 1.5 Mbps channels.

Government procurement costs for three earth stations would be approximately $1,125,000 excluding the cost of studio equipment. The monthly transponder rental fees for three, full-duplex 1.5 Mbps channels would range between $60K and $90K, depending on the satellite carrier.

Although lower data rate service was not the subject of this report, some of the satellite carrier information contained in section 3 showed that this would be a much less costly approach. For example, RCA Americom will lease a 5-meter antenna earth station suitable for their "56 Kbps Plus Service" for $1,500 per month. Transponder time is $1,500 per month for each 56 Kbps increment. Thus, four 56 Kbps channels could be rented for $7,500 per month. Secure voice and data services could share these channels for maximum channel utilization. Any user on the local network with the appropriate digital telephone and encryption equipment could use the secure voice service. Since the voice data would be encrypted before transmission on the local network, the network need not be secure. Other services such as slow scan video and facsimile transmission could be provided as well, with or without encryption.

LIST OF REFERENCES

1. Broadcast Products Directory, M/A-COM Video Systems, Inc., Burlington, MA, 1982, pp. 3-2 - 3-7.

2. ibid, pp. 3-10 - 3-13, 3-18 - 3-19.

3. Bell System Technical Reference, PUB 41451, "1.544 Mbps Digital Service-Channel Interface Specifications (Including 1.344 Mbps Service Option)," AT&T, May 1977.

4. Bell System Technical Reference, PUB 41304, "Wideband Data Set 306-Type Interface Specification, AT&T, July 1971.

5. "Satellite Communications," Auerbach Publishers, Inc., 1981, Section 703.0000-060, pp. 1-8.

6. Data Communications 1982 Buyer's Guide, "Communications Carriers," McGraw-Hill, Inc., New York, NY, November 1981, pp. 12-16.

7. "Overcoming Local and Long-Haul Incompatibility," by Richard H. Sherman, Melvin G. Gable, and Anthony Chung, DATA COMMUNICATIONS, Vol. II, #3, March 1982, p. 206.

8. "Designing Local-Area Networks," Peggy Karp and Ivan Socher, MINI-MICRO SYSTEMS Vol. 15, No. 4, April 1982, p 226.

9. Design and Strategy for Distributed Data Processing, James Martin, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1981.

10. "Slow-Scan TV Holds Promise for Teleconferencing and Other Areas," Glen Southworth, COMMUNICATIONS NEWS, Vol. 19, #2, February 1982, pp. 60-61.

11. "Video Teleconferencing Brings New Direction to Business in the 1980's," Dr. A. Miura, S. Michael Stevenson and David Linker, COMMUNICATIONS NEWS, Vol. 19, #2, February 1982, pp. 52-54D.

APPENDIX A

FIVE-METER REDUNDANT TRANSMIT/RECEIVE
DIGITAL EARTH TERMINAL

COST: $251,000 & OPTIONS

Item	Quantity	Description
A	1	Model 8008 5m dia. antenna including main reflector, mount, anchor bolts and foundation template.
B	1	Subreflector and transmit/receive feed for the Model 8008 5m antenna. Transmit and receive ports are in opposite polarizations.
C	2	100°K low noise amplifiers (LNA) with power supply, alarms and automatic protection switching.
D	1 lot	Material and labor to integrate a 1:1 modem subsystem configured with a 1:N switch and MCU to allow expansion to 1:8 modem subsystem through use of SDM1 and SDM2.

E	1 lot	Material and labor to integrate an expansion rack that allows SDMCI to be expanded from the 1:1 modem configuration up to a 1:5 modem configuration or to add four on line modems to SDCN non-redundant configuration.
F	1 lot	Material and labor to integrate an expansion rack that allows SDMCE/SDM1 to be expanded from a 1:5 modem configuration to a 1:8 modem configuration or to add up to four on line modems to SDCN/SDM1 configuration.
G	1 lot	Material and labor to integrate redundant HAP and up/down converters in a 6′ x 8′ x 8′ shelter located adjacent to antenna. Includes necessary switching assemblies to place alternate LNA/downconverter on HPA/upconverter sets on line and 200 ft of interfacility link cables to interface with a modem subsystem located within customer facilities.
H	2	400W TWTA high power amplifiers, two-port divider, waveguide switch, power supplies and alarms self-contained in a single equipment rack.

I	2	Consists of high stability Model 8363-5CH upconverter and 8632-5CH downconverter. Each converter is frequency-selectable by internal crystal, allowing for up to six crystals to be installed. One crystal is supplied with unit.
J	2	Model 8801-56 modulator set for an input information rate of 56 Kbps. Includes a rate 7/8 forward error correction convolutional encoder and uses QPSK modulation.
K	2	Model 8802-56 demodulator set for an input information rate of 56 Kbps. Includes a rate 7/8 threshold decoder for forward error correction and uses QPSK modulation. If frequency is selected by specifying a fixed frequency plug-in crystal.
L	1	Remote Reporting Option. Used with MCU to remotely report station status via a telephone line.
M	1	Model 8813 modulator/coder and demodulator/decoder in a single unit. Uses rate 7/8 FEC coder and decoder and QPSK modulation (1.544 Mbps (T1), QPSX).

N	1	Model 8802-56 demodulator set for an input information rate of 56 Kbps. Includes a rate 7/8 threshold decoder for forward error correction and uses QPSK modulation. IF frequency is selected by specifying a fixed frequency plug in crystal.
O	1	Model 8801-56 modulator set for an input information rate of 56 Kbps. Includes a rate 7/8 forward error correction convolutional encoder and uses QPSK modulation.
P	1	Model 8863 dual synthesizer. Provides transmit and receive IF frequencies to drive modems in frequency agile mode.
Q	1	Model 8240-5 automatic feed, subreflector and half main reflector deicing for the Model 8008 5m antenna. Includes heaters, power contactor, sensors, multiconductor control cable and automatic control unit.

All cable lengths to be 100 ft.

APPENDIX B

TEN-METER REDUNDANT TRANSMIT/ RECEIVE EARTH STATION

Cost: $373,000

Item	Quantity	Description
A	1	Model 8002, 10m diameter antenna with main reflector, azimuth-over-elevation mount, anchor bolts and foundation template. Includes high-speed motor drives package (110°/min) azimuth coverage with no mechanical changes. Includes three axis programmable automatic position control unit, high-speed motor drives and multi-conductor control cable.
B	1	Subreflector and transmit/receive feed for the Model 8002 10m antenna. Transmit and receive ports are in opposite polarization.
C	2	120°K low noise amplifiers (LNA) with power supply, alarms, and automatic protection switching.

D	2	Model 7500 synthesized, microprocessor-controlled, 24-channel video receivers with both 6.2 MHz and 6.8 MHz audio subcarrier demodulators and automatic switching. Expandable to 2:N protection capability with additional Model 7500 receivers.
E	2	2.8 kW high power amplifier (HPA) with automatic protection switching, hybrid combiner and loads to allow occasional transmission of two simultaneous uplinks.
F	2	Model 461 frequency-synthesized video exciters with automatic baseband input switching and RF output switching. Each exciter also includes group delay equalization.
G	2	Model 415 program audio unit for audio modulation on two subcarriers (6.2 and 6.8 MHz) and alarm modules with two video low-pass filters.
H	1	Model 460 Loop Test Translator
I	2	Standard 7 ft. equipment racks with transmit/receive equipment installed.

J	1 lot	Integration hardware including waveguide, waveguiJe support system, coax cable with connectors, automatic pressurization/dehydrator and all miscellaneous hardware for a complete operational system.
K	1 lot	Installation, checkout, video proof of performance and on-site training of station personnel of transmit/receive earth station. Assumes antenna foundation, AC power, and conduit runs will be provided by others. Assumes space for ground communications equipment and venting for the HPAs are available in an existing equipment room adjacent to the antenna site. Site clearing, permits, and special cabling required by local codes are to be provided by others.
L	1	Transmit reject filter for LNA subsystem.

OPTION

TEN-METER TRANSMIT/RECEIVE WITH FULL TRANSPONDER
VIDEO TRANSMISSION AND 1.544 Mbps TRANSMISSION CAPABILITY

Cost: $602,000

END

FILMED

4-84

DTIC